HYDRAULIC POWER AND HYDRAULIC MACHINERY.

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BY

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TO

THE RIGHT HONOURABLE LORD ARMSTRONG,

C.B., LL.D., D.C.L., F.R.S.,

The Originator of the Modern Hydraulic System,

THIS WORK IS CORDIALLY INSCRIBED

IN GRATEFUL ACKNOWLEDGMENT

Of much kindness shown in bygone days

TO HIS FORMER ASSISTANT,

THE AUTHOR.

PREFACE TO THE FIRST EDITION.

The increasing interest taken in Water-pressure Machinery, and the extended field which has opened out of late years for its employment, have led me to record, in a form convenient for reference, existing experience in this branch of Engineering. In this task I have availed myself of the information published in the *Proceedings* of the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Iron and Steel Institute, and of other Societies. I have thus not confined myself within the range of my own professional practice, but have utilised the experience of others wherever I have found that it would increase the usefulness of the book.

It affords me much pleasure to acknowledge the ready response that has invariably followed any request for particulars or for drawings to enable me to illustrate the varieties of Hydraulic Apparatus to which I desired to refer, and I believe that I have recognised in the proper places throughout the work my obligations to all who have thus kindly assisted me.

At the commencement, I refer briefly to the "Flow of water under pressure," and show the practical value of some interesting experiments which have recently been made, and which have enabled new formulæ to be deduced for the discharge from pipes. The employment of water-pressure mains, to transmit power through the streets of a town on

the principle which I have termed "Power co-operation," is steadily gaining ground. The first works of the kind were those which I carried out in Hull in 1876, and the promotion of similar undertakings in other towns will afford an increased field for utilising hydraulic power.

Whilst describing the most interesting types of Hydraulic Machinery, I have abstained alike from criticisms on the details of construction, and from any attempts to lay down fixed rules for the employment of any particular appliance. The conditions which render one form of appliance more suitable than another vary in almost every case, so that each requires to be dealt with according to the practical circumstances which govern it.

As my earliest experiences in this branch of my practice were gained nearly thirty years ago, when with Sir William (now Lord) Armstrong, I have dedicated this book to him; and his friendly acceptance of this dedication has enabled me, in these later days, to refer to an association which I look back upon with pleasure and pride.

HENRY ROBINSON.

November 1886.

PREFACE TO THE THIRD EDITION.

SINCE the Second Edition of this book was prepared, Hydraulic Power has been employed for many other purposes than those to which I then referred; and as the necessity has arisen either of reprinting the book as it stands, or of revising it, I have thought that, by incorporating some more recent information which is available, the usefulness of the book would be thereby enhanced. This view has been encouraged by many professional friends whose opinion I value, and whose aid has been readily afforded me. I desire to acknowledge the assistance that I have received from my sons Keith and Leigh.

HENRY ROBINSON.

PARLIAMENT MANSIONS,
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AND

HYDRAULIC MACHINERY.

THE weight of a cubic foot of distilled water is 62·499 lbs. avoirdupois at a temperature of 39° Fahrenheit. At a temperature of 62° the weight of a cubic foot of water is 62·355 lbs. Although water has been proved by experiment to be compressible (but very slightly) under great pressures, for all practical purposes it is taken as incompressible. The compressibility of water is one twenty-thousandth for an increase in pressure equivalent to an atmosphere.

DISCHARGE THROUGH ORIFICES.

Torricelli discovered in 1643 that the velocity of a fluid flowing through an orifice in a vessel is approximately equal to that which a solid body would acquire in falling a height corresponding to the distance between the level of the fluid in that vessel and the centre of the orifice. Employing symbols to represent this:—If v is taken for the velocity in feet per second, H for the difference of level or head in feet, and g for the measure of the accelerating force of gravity, or the number of feet per second at which a

falling body is moving at the end of the first second (equal to about 32·2),

Then

$$v = \sqrt{2gH}$$

or

$$v = 8{\cdot}024\ \sqrt{H}$$

If to the natural head (H) be added artificial pressure (H^1), then

$$v = 8{\cdot}024\ \sqrt{H+H^1}$$

The quantity discharged from an orifice is proportional to the area of the opening and the velocity. As the sectional area of the

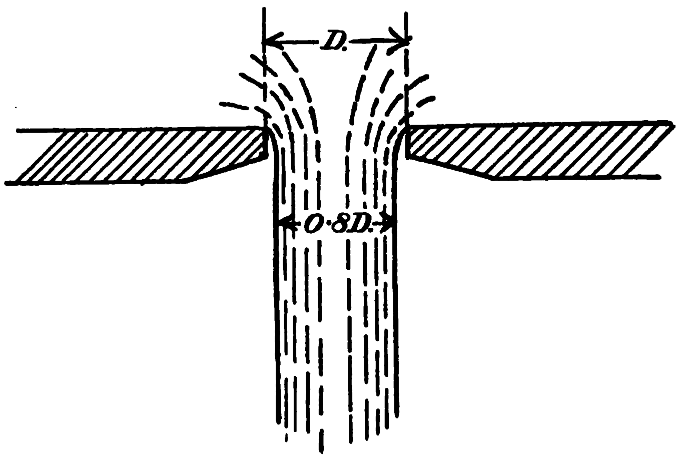


Fig. 1.

jet is less than the area of the orifice, the quantity discharged is not found by multiplying the area of the opening by the velocity, but a coefficient has to be applied to represent the extent of the reduction of the area of the jet (called the Vena Contracta).

If

Q = Discharge in cubic feet per second.
A = Area of the orifice in square feet.
C = A coefficient.

Then

$$Q = C.A \times 8{\cdot}024\ \sqrt{H}$$

The amount of the reduction in the area of the jet, caused by the Vena Contracta, depends upon the shape and the edges

of the orifice and upon the head. If the orifice is circular, and its inner edge is perfectly sharp, the diameter of the issuing jet will be about 80 per cent. of the diameter of the orifice, or the area of the jet will be about ·64 that of the orifice. The value of the coefficient C in the above expression will be generally less than ·64. This form of jet is shown by fig. 1.

The following Table gives the results of experiments, with sharp-edged circular orifices, by various observers in the past:—

Experimenter.	Head.	Diameter of Orifice.	Coefficient.
	Feet.	Inch.	
Eytelwein, ...	2·4	1·0	0·618
Bossut, ...	0·6	1·0	0·649
Castel, ...	2·7	1·2	0·629
Venturi, ...	2·9	1·6	0·622
Rennie, ...	1·0	1·0	0·633
,, ...	2·0	1·0	0·619
Weisbach, ...	2·0	1·2	0·614
,, ...	2·0	1·6	0·607
,, ...	0·8	1·2	0·622
,, ...	0·8	1·6	0·614

Experiments were made by the late Mr James Simpson and Mr John G. Mair-Rumley, and the results (communicated to the Institution of Civil Engineers) are given in the following Table:—

COEFFICIENTS OF DISCHARGE FROM CIRCULAR ORIFICES.

Temperature 51° to 55° Fahr.

Head. Inches.	Approximate Diameter of Orifice in Inches.								
	1	1¼	1½	1¾	2	2¼	2½	2¾	3
	Absolute Area in Square Feet.								
	0·00546	0·00852	0·012281	0·016749	0·021806	0·027576	0·033898	0·040933	0·049139
	Coefficients.								
9	0·616	0·614	0·616	0·610	0·616	0·612	0·607	0·607	0·609
12	0·613	0·612	0·612	0·611	0·612	0·611	0·604	0·608	0·609
15	0·613	0·614	0·610	0·608	0·612	0·608	0·605	0·605	0·606
18	0·610	0·612	0·611	0·606	0·610	0·607	0·603	0·607	0·605
21	0·612	0·611	0·611	0·605	0·611	0·605	0·604	0·607	0·605
24	0·609	0·613	0·609	0·606	0·609	0·606	0·604	0·604	0·605

Professor Unwin has deduced, from this Table, the following formula for the coefficient of discharge, which is applicable within a limited range :—

$$C = 0{\cdot}6075 + \frac{0{\cdot}0098}{\sqrt{H}} - 0{\cdot}0037D$$

where H is the head in feet, and D is the diameter in inches.

Orifices of this form afford a very convenient method of gauging the flow of water during trials of engines and hydraulic machinery, but the variable coefficient has always been a draw-back. With a view to obviate this Mr Edgar Thrupp has examined the experiments on 37 different orifices with the following results :—

(1) The discharge is not proportional to the square root of H, unless the diameter of the orifice is about 6 inches.

(2) The area of the jet is not proportional to the area of the orifice, but is more nearly proportional to $D^{1{\cdot}98}$ (D being the diameter of the orifice) when H is 1 foot.

If

Q = discharge in cubic feet per second,
H = head of water in feet,

and

D = diameter of orifice in feet,

the following formula is arrived at from the 37 orifices :—

$$Q = 3{\cdot}715\, D^{1{\cdot}98} \sqrt[n]{H}$$

and

$$n = 1{\cdot}97 - 0{\cdot}08 \log D.$$

Some experiments on orifices, 1 foot and 2 feet in diameter, give values of n as about 1·97 and 1·95 respectively, while other experiments on orifices less than one-third of an inch in diameter show "n" as high as 2·15.

After determining D, the formula may be simplified to

$$Q = x \sqrt[n]{H}.$$

As an example, take $D = {\cdot}25$ foot.

Then $n = 2{\cdot}02$ and $x = 2{\cdot}39$ and

$$Q = 2{\cdot}39 \sqrt[2{\cdot}02]{H}$$

Table showing the Degree of Accuracy of the Formula $Q = 3{\cdot}715\, D^{1{\cdot}96} \sqrt{H}$ based on 216 Experiments on the Discharge of 37 sharp-edged *Circular Orifices*.

Name of Observer.	Number of Experiments.	Diameter of Orifice in feet.	Head of Water in feet.		Mean Error of Formula	
			Maximum.	Minimum.	+ per cent.	– per cent.
Ellis, ...	7	2·0	9·64	1·77	...	– 1·70
Hamilton-Smith,	1	1·01	1·05	1·05	...	– 2·00
Ellis, ...	10	1·00	17·72	1·15	+ 1·43	...
Hamilton-Smith,	1	0·66	1·09	1·09	+ 0·28	...
Michelotti, . .	2	0·53	12·0	6·9	...	– 0·71
Ellis, ...	13	0·50	17·26	2·15	...	– 0·28
Hamilton-Smith,	1	0·419	1·20	1·20	...	– 0·45
Michelotti, . .	1	0·270	12·50	12·50	...	– 1·96
Hamilton-Smith,	1	0·253	1·33	1·33	...	– 1·51
Mair-Rumley, .	6	0·2501	2·00	0·75	...	– 0·19
,, . .	6	0·2283	2 00	0·75	0·00	– 0·00
,, . .	6	0·2078	2·00	0·75	+ 0·47	...
,, . .	6	0·1874	2·00	0·75	+ 0·36	...
Michelotti, . .	1	0·18	7·20	7·28	...	– 0·91
Bossut, . .	1	0·178	12·50	12·50	...	– 3·10
Mair-Rumley, .	6	0·1666	2·00	0·75	...	– 0·32
,, . .	6	0·1460	2·00	0·75	+ 0·56	...
Weisbach, . .	2	0·13	2·00	0·82	+ 1·45	...
Mair-Rumley, .	6	0·1250	2·00	0·75	+ 0·21	...
,, . .	6	0·1041	2·00	0·75	+ 0·34	...
Hamilton-Smith,	19	0·10	4·62	0·129	+ 1·05	...
Weisbach, . .	2	0·10	2·00	0·82	...	– 0·42
Bossut, . .	1	0·089	12·50	12·50	...	– 3·00
Mair-Rumley, .	6	0·0834	2·00	0·75	+ 0·83	...
Weisbach, . .	2	0·066	2·00	0·82	...	– 0·79
Hamilton-Smith,	21	0·0498	4·63	0·185	+ 0·42	...
Bossut, . .	1	0·044	12·50	12·50	...	– 2·48
Weisbach, . .	7	0·033	340·0	0·066	...	– 4·23
Steckel, . .	3	0·032	4·2	1·00	...	– 0·74
Thrupp, . .	4	0·02783	1·416	0·583	...	– 3·63
,, . .	6	0·02758	1·50	0·475	...	– 4·17
,, . .	14	0·02700	1·75	0·527	...	– 3·78
,, . .	11	0·0212	1·75	0·458	...	– 3·36
Hamilton-Smith,	3	0·020	3·19	0·739	...	– 1·11
Thrupp, . .	9	0·0185	1·75	0·518	+ 3·24	...
,, . .	8	0·0148	1·75	0·500	...	– 3·94
,, . .	10	0·00925	1·708	0·496	+ 4·00	...
Total— 37 Orifices.	216 Experiments.		340·0 Extremes.	0·606		

The error per cent. is called "plus" when the formula gives more than the observed discharge.

The above shows a mean error of minus 0·82 per cent. Omitting the last 11 orifices (in which slight errors in the measurement of the diameter largely affect the results), the remaining 26 orifices show a mean error of only minus 0·38 per cent.

From the above Table it appears that if results are required within 0·5 per cent., the orifice must be tested to obtain its coefficient "x."

The temperature of water has a slight effect upon the coefficient

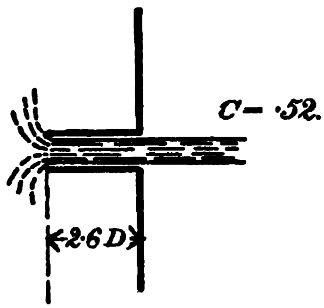


Fig. 2.

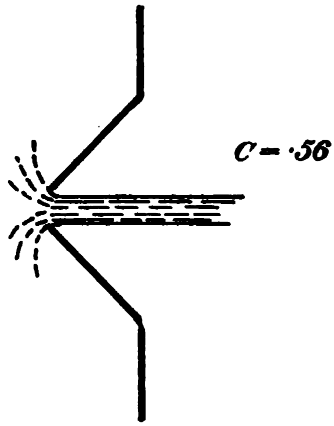


Fig. 3.

of discharge from an orifice. Experiments made by Mr Mair-Rumley show that with a sharp-edged orifice 2¼ inches in

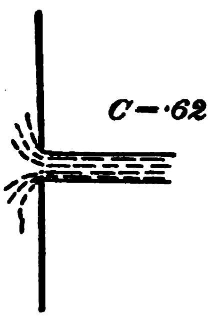


Fig. 4.

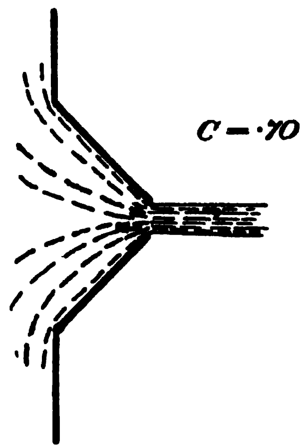


Fig. 5.

diameter, and with a head of 21 inches, the coefficient C was ·604 for temperatures varying from 57° up to 110°, and increased to ·607 for temperatures up to 179°.

The accompanying figures show the effect of the shape of the outlet upon the coefficient of discharge C in the formula $Q = C A \times 8{\cdot}024 \sqrt{H}$:—The greatest contraction of the jet occurs with a short tube projecting into the vessel (fig. 2),

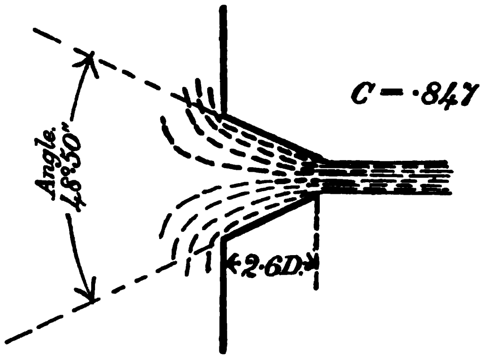


Fig. 6.

giving a coefficient of ·52. Fig. 4 shows the sharp-edged orifice in a flat plate, as in fig. 1. Figs. 6, 7, 9, and 10 are from Castel's experiments. In fig. 10 the coefficient ·829 only applies in case the short tube projecting out of the vessel runs full at the outlet, as it generally does; but if the jet escapes

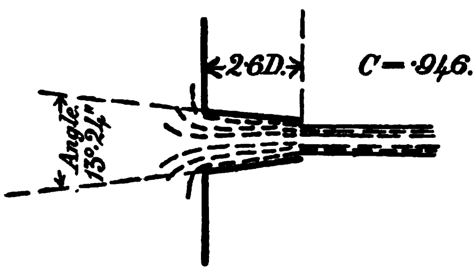


Fig. 7.

without touching the sides of the tube, and the internal edge is perfectly rectangular, the coefficient will be reduced to ·62. Fig. 8 is from the experiments of Mr Hamilton-Smith, jun., on the nozzles used in California for directing a jet of water against the working faces in gold mines under a head of over

300 feet. Fig. 11 is from Venturi's experiments with divergent mouthpieces, which showed that the discharge of an orifice

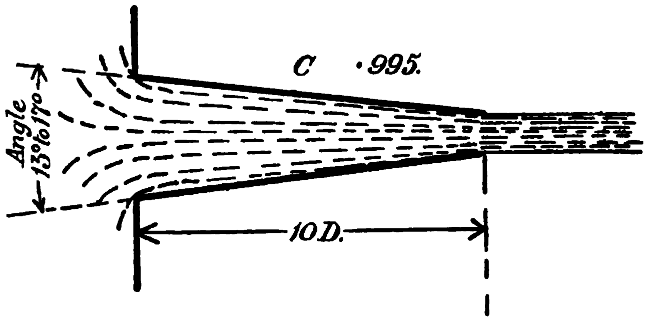


Fig. 8.

could be increased by placing a cone of this description on the outlet. The greatest increase was found with an angle of

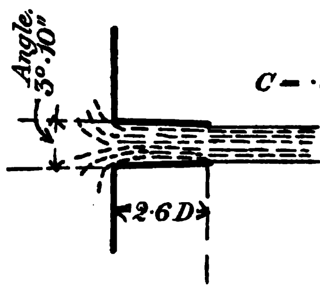


Fig. 9.

divergence of 5° 6′ in a cone having a length of nine times the diameter of the orifice. The increase is due to the fact that the

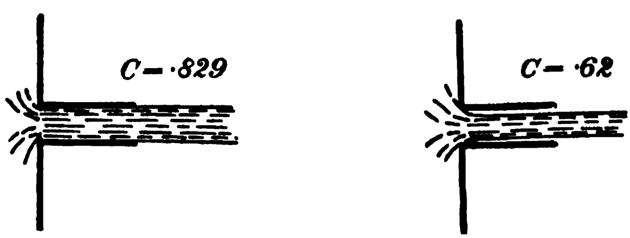


Fig. 10.

velocity of water after passing through the orifice is gradually reduced before the free discharge takes place, and the head due

to this reduction of velocity assists the statical head upon the orifice. This discovery is of great practical value. If, however,

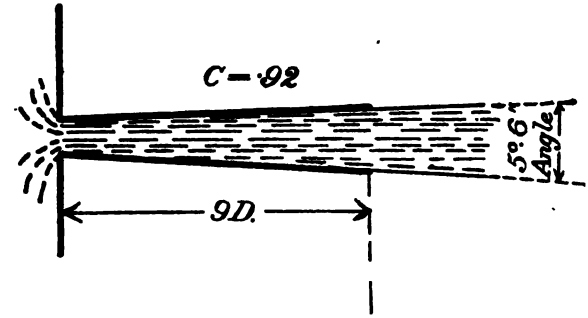


Fig. 11.

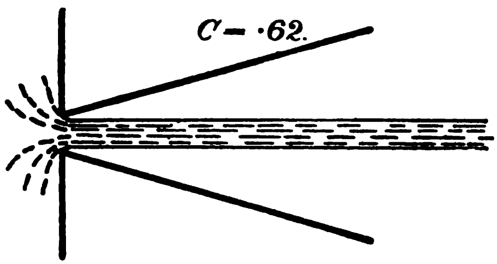


Fig. 12.

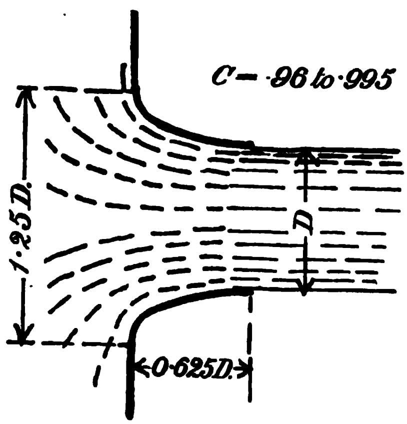


Fig. 13.

the divergence is too great, as in fig. 12, the advantage is lost. Fig. 13 shows what is called a "conoidal orifice," which is

shaped to correspond with the natural form of a jet from a sharp-edged orifice, with the result that the coefficient reaches from ·96 to ·995. In all the cases where the outlet is tapered the diameter is measured at the narrowest part. The sharp-edged orifice in a flat plate is the easiest form to reproduce, and gives results, for any given diameter and head, as uniform as any other kind of orifice, and is, therefore, the most suitable for accurate gauging purposes.

WEIRS.

Gauging Water by Weirs.

For gauging running water it is often more convenient to use a sharp-edged weir instead of an orifice, particularly for large volumes flowing in open channels. The theoretical formula for the flow over a weir is

$$Q = C\,l\,H + \tfrac{2}{3}\sqrt{2gH}$$

Where

Q = discharge in cubic feet per second.
l = length of weir in feet.
H = head of water in feet.
C = a coefficient allowing for contraction, etc.

The head is measured from the level of the edge or sill of the weir to the level of the surface of the water, a short distance up stream, at a point sufficiently removed from the weir to avoid the curve of the surface approaching the overfall (see fig. 14).

The coefficient C is found to be about the same as that for sharp-edged orifices, namely, from ·59 to ·62, according to the head and the length of the weir. It is also affected by the size of the channel approaching the weir. If the depth of water behind the weir is at least 4 H, and if the channel extends at least 3 H beyond the end of the weir at the level of the sill, then the contraction is said to be "complete," and

the velocity of approach will be insignificant. For accurate gaugings these conditions should be fulfilled.

In the event of the flow over the weir not being free of the notch (and therefore not as shown by fig. 14) but passing

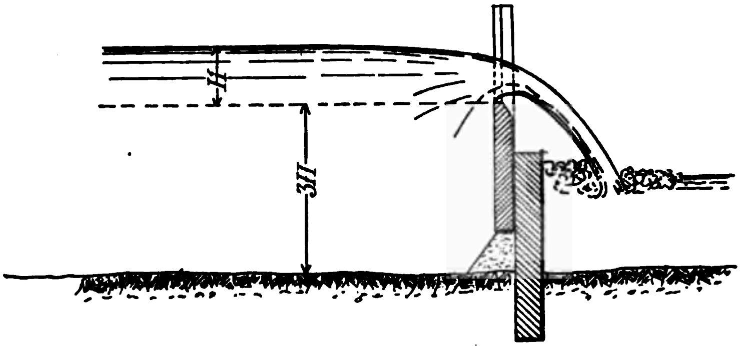


Fig. 14.

in contact with the outer part of the weir, so that air is expelled from the lower side of the weir to the face to which the sheet of water adheres, then the pressure close to the face is below that of the atmosphere, and the flow is considerably increased compared to the case of free discharge.[1]

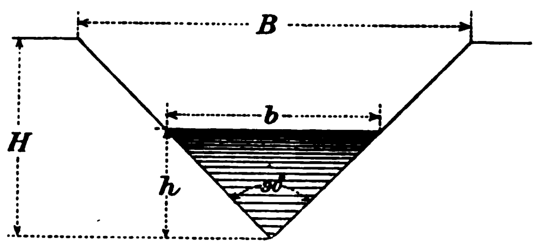


Fig. 15.

For gauging streams of small and variable velocity a triangular notch is most suitable as shown in fig. 15.

The discharge can be calculated by the formula—

$$Q = C \frac{4}{15} B \sqrt{2gH^3}$$

(the dimensions being in feet), C being the coefficient allowing

[1] *Trans. Inst. C.E.*, vol. cxvii. p. 421.

for contraction. It is much more constant in a Vee-shaped notch than in a rectangular notch, as the flow is always similar at whatever height the water is discharged through the notch.

When running at any depth other than full, B and H become b and h in the formula, and its area computed. As the bottom and sides are irregular, straight lines have to be substituted as shown by fig. 16. The calculation is given for ascertaining the "hydraulic mean depth" which is the sectional area of

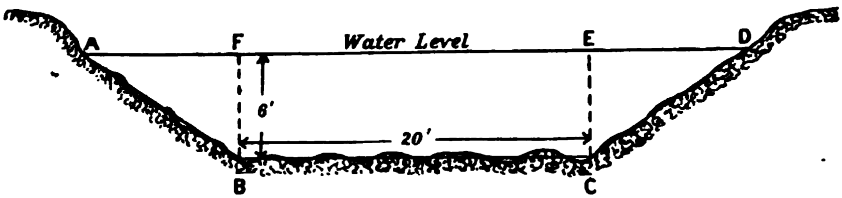


Fig. 16.

water divided by the wetted perimeter (or the line $A\ B\ C\ D$). The slopes $A\ B$ and $C\ D$ are found to be $1\frac{1}{2}$ to 1, so that—

$$A\ B \text{ and } C\ D = \sqrt{9^2 + 6^2} = 10'{\cdot}8$$

and the wetted perimeter

$$= 20' + 10'{\cdot}8 + 10'{\cdot}8 = 41'{\cdot}6.$$

The water surface

$$A\ D = 20' + 2\ (6' \times 1\tfrac{1}{2} \text{ to } 1) = 38'.$$

The sectional area therefore is $\frac{20 + 38}{2} + 6 = 174$ feet, and the hydraulic mean depth is thus $\frac{174}{41{\cdot}8} = 4{\cdot}18$ feet.

Screw "current meters" afford a means of ascertaining the mean velocity of a stream, as the meter can be placed in all parts so that the average flow is recorded. To obtain reliable results, however, it is necessary to find the "constants" of the meter by towing it in still water.

To ascertain the "discharge" of a stream where gauges

cannot be conveniently fixed, floats are employed by which the velocity of flow is determined. As this varies, being least at the sides and bed of the stream, the float observations should not be confined to merely recording surface velocity. To determine the mean velocity it is essential to make a series of observations of velocity at points across the section of the stream. If there is no wind which can either retard or accelerate the movement of a light float, the surface velocity can be found by observing the time occupied by the float during its passage down the stream between two definite points at known distances apart. By suspending a cord with a weight attached to a piece of wood or cork (the length of the cord being arranged to avoid touching the shallowest part of the stream), the average velocity, as distinguished from the surface velocity, can be determined. A bottle or tin case weighted, so that all but the top is submerged, serves as a float when there are currents of air likely to interfere with the observations. Having made float records both in the middle and other parts of the stream, the "discharge" requires the sectional area of the stream to be ascertained. If it is a small stream, this can be done by stretching a line across it, at right angles to the line of flow, and taking soundings at definite points along the line, so that a section of the channel can be plotted.

FLOW OF WATER THROUGH PIPES.

Water flowing through a pipe or channel has to overcome the friction caused by its movement along the interior surface of the pipe or the bed of the channel. The amount of the friction is measured by the force that is necessary to overcome it. In a conduit of uniform section, this force is the head or loss of pressure ("h") in a given length ("l") multiplied by the sectional area of the conduit (A).

In an open channel "h" is represented by the fall of the surface line (fig. 17), the slope of which is called the "hydraulic

gradient." In the case of a pipe running full under pressure (fig. 18), "h" is the difference of the levels to which the water would rise in similar branch pipes, open at the top and placed at each end of the length "l." If the water is at rest in the pipe the level will be the same at the points C and D, but if

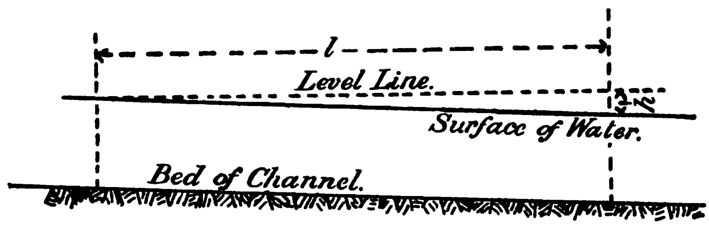


Fig. 17.

there is a flow from A to B, then the level at D will fall below that at C, and the line $C\ E$ represents the hydraulic gradient.

At small velocities "h" is found to be roughly in simple proportion to the mean velocity v, but at higher velocities "h" varies in proportion to $v^{1\cdot70}$ to v^2 according to the nature of the surface of the conduit. The smoother the surface the lower the index of v.

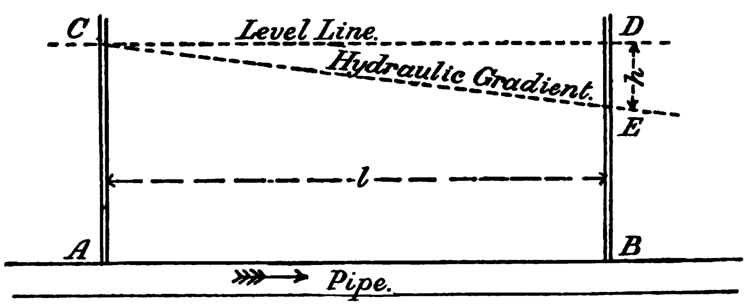


Fig. 18.

The nature of the surface is found to have a large influence upon "h" independent of its effect upon the index of v. The temperature also has an influence on the discharge.

It has been said that the moving force is $h \times A$; A being the sectional area of the conduit which is filled with water.

The resulting mean velocity depends not only on the nature, but also on the area, of the surface in contact with the water, the area being a multiple of "l." This multiple is called the "wetted perimeter" (P). In the case of a pipe, P is the circumference of a circle having the same diameter as the inside of the pipe. It follows, theoretically, that v is in some way proportional to $\frac{h \times A}{l \times P}$. For convenience it is preferable to divide l by h to obtain the cosecant of the angle of inclination of the hydraulic gradient (S), and to divide A by P to obtain a factor representing the shape and size of the conduit which is called the "hydraulic radius" (R). This, although only a theoretical factor, serves its purpose remarkably well, except in the case of wide and shallow open channels with very irregular beds.

It may, therefore, be stated that the mean velocity v is *in some way*—

1st, directly proportional to $R\left(\text{or } \frac{A}{P}\right)$;

2nd, inversely proportional to $S\left(\text{or } \frac{l}{h}\right)$;

3rd, inversely proportional to the roughness of the surface;

4th, directly proportional to the temperature.

The actual proportions can only be arrived at by experiment, so it is necessary to use different coefficients or constants to meet the circumstances of the case. A simple equation adapted to suit the various conditions is the following modification of a formula arrived at by Dr G. Hagen:—

(1) $$v = \frac{R^x}{C\sqrt[n]{S}} \times \left(1 + \frac{T - 50}{K}\right)$$

v = the mean velocity in feet per second.

R = the hydraulic radius in feet.

S = the cosecant of the angle of inclination of the hydraulic gradient $= \frac{\text{length}}{\text{head}}$.

C = a coefficient (representing the roughness of the surface).

T = the temperature of the water in degrees Fahrenheit.

The index "x" and the root "n," as well as the coefficient "C," depend on the nature of the surface; they have distinct values for velocities above and below what is called the "critical velocity," which is referred to more fully hereafter.

"K" is the temperature coefficient, which has only two values: 600 above the critical velocity and 200 below that velocity.

(If the velocity were simply proportional to the absolute temperature, "K" would be 510 or 460 + 50, as the coefficients "C," given in the Table on p. 17, are worked out to apply to a temperature of 50° Fahr., so that for many practical purposes the "temperature coefficient" may be neglected.)

Below the "critical" velocity "n" may be taken as 1·00, "K" as 200, and "x" as 1·70, thus reducing the equation (1) to the form

(2) $$v = \frac{R^{1\cdot70}}{C\,S} \times \left(1 + \frac{T - 50}{200}\right).$$

In dealing with the flow of water through pipes, it is generally more convenient to use a formula for discharge instead of for velocity.

If

Q = discharge in cubic feet per second,
D = diameter of pipe in feet,

and

P = coefficient in place of "C,"

(3) $$Q = \frac{D^{2+x}}{P\,\sqrt[n]{S}} \times \left(1 + \frac{T - 50}{600}\right)$$

for velocities above the critical point; and

(4) $$Q = \frac{D^{3\cdot7}}{P\,S} \times \left(1 + \frac{T - 50}{200}\right)$$

for velocities below the critical point. The coefficient "P" in equation (3) is related to "C" in equation (1) thus—

$$P = C \times \frac{7}{88} \times 4^{(2+x)}.$$

The 2 added to "x" in the index of "D" is derived from the

variation of the area in proportion to the square of the diameter.

TABLE OF COEFFICIENTS RELATING TO EQUATION No. 1, P. 15, AND EQUATION No. 3, P. 16, AND APPLICABLE FOR VELOCITIES MORE THAN 20 PER CENT. GREATER THAN THE CRITICAL VELOCITY.

Factor to which the coefficient relates.	Velocity.	Roughness.	Hydraulic Radius.	Temperature.	Roughness.
Description of surfaces.	n	C Formula No. 1.	x	K	P Formula No. 3.
Lead, Tin, Copper, &c., .	1·75	0·005224	0·62	600	·015704
Cast Iron, new,[1] . A,	1·85	0·005347	0·67	600	·01723
Cast Iron, new,[1] . B,	2·00	0·006752	0·63	600	·020584
Old Cast Iron, ...	2·00	0·017115	0·66	600	·03353
Ditto cleaned, ...	1·95	0·0074191	0·64	600	·02293
Wrought Iron, new, . .	1·80	0·004787	0·65[2]	600	·015002
Rivetted Sheet Iron, . .	1·325	0·005674	0·677	600	·018459
Pure Cement rendering,[1] . . . . . A,	1·74	0·004000	0·67	600	·012391
Pure Cement rendering,[1] . . . . . B,	1·95	0·006429	0·61	600	·019061
Brickwork, in good condition, ...	2·00	0·007746	0·61	600	·022965

When the velocity "v" or the discharge "Q," by equations (1) or (3) work out higher than by equations (2) or (4), the latter are the correct ones to use. When they work out the same, the velocity is a little below the critical velocity, and equations Nos. 2 and 4 will hold good up to a point at which they give "v" or "Q" about 25 per cent. higher than equations 1 or 3. This is the "Critical Point," where the value of "n" suddenly changes from 1·00 to about 4·00. At all velocities more than 20 per cent. higher than the critical velocity equations 1 and 3 hold good.

Putting it another way:—When equations (2) and (4) give results from 25 to 50 per cent. higher than (1) and (3), the conditions are in the critical region where "n" = 4·00. At

[1] Other coefficients will be found in the *Transactions of the Society of Engineers* for December 1887. Those given in the above Table have been slightly altered to refer to a temperature of 50° F. For high velocities the set of coefficients marked B should be used, and for medium velocities the set marked A. Whichever set gives the lowest velocity is the correct one to use.

[2] For pipes less than ·28 foot diameter, when great accuracy is required, take $x = \cdot 65 + \cdot 018 \sqrt{\frac{\cdot 28 - D}{D}}$.

higher velocities (1) and (3) hold good, and at lower velocities (2) and (4) hold good.

The coefficients relating to Equation No. 4 appear to differ very slightly from one another for pipes of the same size. Taking $n = 1$ and $x = 1{\cdot}70$, P comes out at ·00005 for lead pipes and ·000046 for wrought-iron pipes. For pipes between $\frac{1}{4}$ of an inch and 3 inches in diameter, the formula may be taken as

$$Q = \frac{D^{3 \cdot 7}}{\cdot 00005 \times S}\left(1 + \frac{T - 50}{200}\right).$$

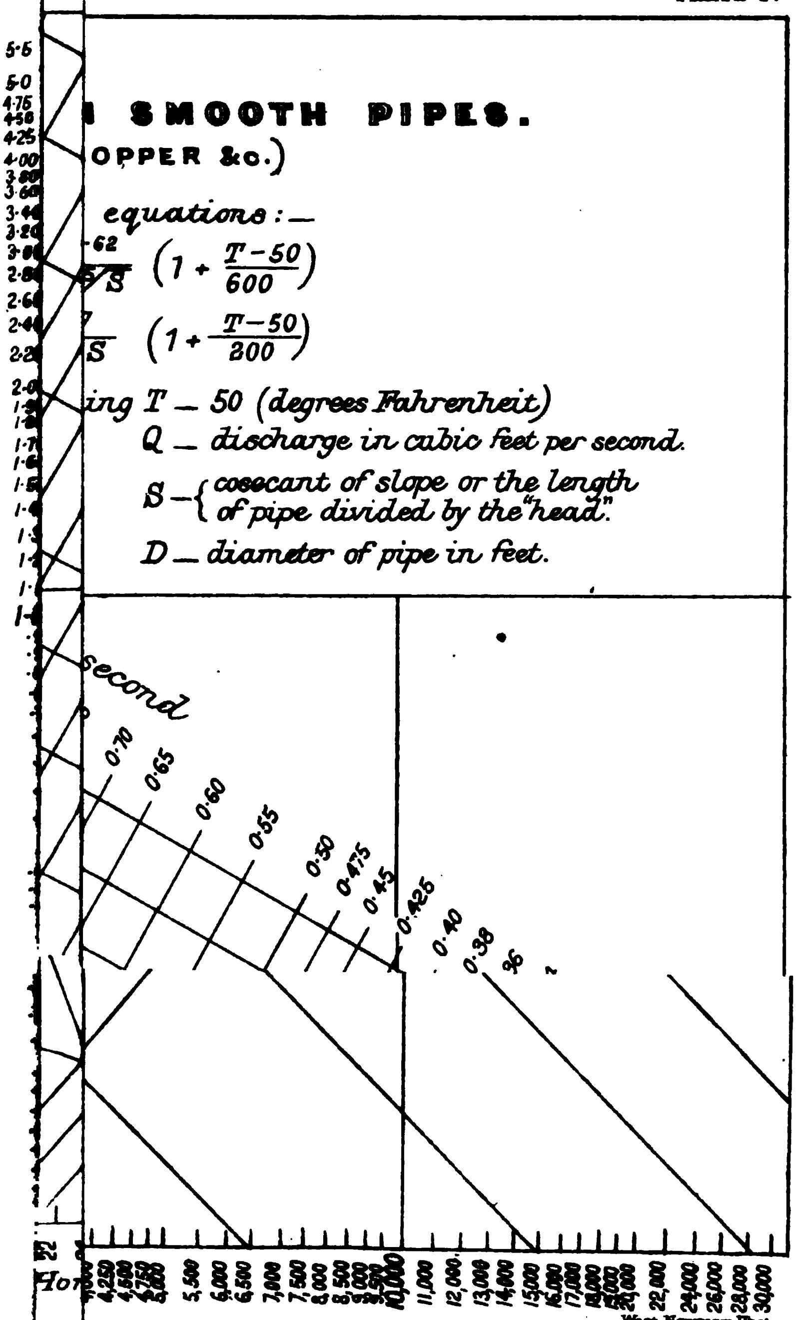
This has been used in plotting the portion of Plate 1, which refers to the region below the critical point. The index of D bears some kind of inverse proportion to D, reaching a maximum value of about 4 for very small tubes.

When there are variations in the size of a closed channel producing a divergence in one direction of flow, and a convergence in the other, Mr T. E. Shanton, in a communication to the Institution of Civil Engineers, points out that the loss of head of water flowing as a diverging current, to a state in which the kinetic energy is negligible, is about 25 per cent. of the initial velocity head, and that when the direction of flow is reversed the loss of head is about 10 per cent. of the final velocity head. These ratios are the same for a range of velocity from 11 to 30 feet per second at the least section.

In calculating the discharge from large water mains the following is deserving of record. The late Mr Parker Neville, the engineer who carried out the Dublin Corporation Waterworks, stated that the 33-inch main was calculated as being capable of conveying from 15 to 16 million gallons of water per diem, but in practice it was found capable of conveying about 20 million gallons. The late Mr Bateman mentions in his *History of the Manchester Waterworks* that the calculated delivery of water in large mains proved to fall much below the actual quantities delivered.

The calculated quantities were estimated by Eytelwein's formula as follows:—

PLATE I.



West, Newman Photo.

If d, h, and l be respectively the diameter, height, and length of the pipe in feet, and v be the velocity of discharge in feet per second, then

$$V = \frac{\sqrt{2500 \times dh}}{(l + 50\,d)}.$$

The delivery of water as calculated by this formula (where coated pipes were used) proved to be much more in practice, especially in the case of pipes of large diameters, and a nearer approximation was obtained by Bazin's formula as follows:—

$$R\,I = A\,V^2,$$

or

$$V^2 = \frac{R\,I}{A}.$$

Where

R = hydraulic mean depth,
I = sine of inclination,
V = mean velocity,
A = coefficient.

$$\text{value of } A = 0{\cdot}0000457\left(1 + \frac{0{\cdot}0984}{R}\right).$$

The *Transactions of the American Society of Civil Engineers* for 1896 contain some interesting experiments on the discharge from 48-inch pipes in connection with the water supply for Boston. They showed that the coefficient was 70 with a velocity of 3·74 feet per second, 71 with a velocity of 4·96, and 72 with a velocity of 6·19.

A paper contributed by Mr G. M. Lawford to the Institution of Civil Engineers in 1903 on the flow of water in long pipes contains much useful information, and deserves to be recorded for reference by those who wish to pursue the subject further.

The necessity for properly coating a water main cannot be too strongly insisted upon. The proportions for the coating, and the temperature at which it is applied, must be in accordance with well-known practical conditions. Instances are known where the non-compliance with these conditions has resulted in an absorption by the water of the tarry compounds of the coating, causing the water to be unfit for consumption.

The life of a pipe is greatly prolonged if it is properly coated. A case is recorded by Mr Ingham (in connection with the water supply of Torquay) where an old water main which was laid before the introduction of Dr Angus Smith's coating lost 50 per cent. of its discharging capacity in eight years through the corrosion of the pipe. To remove the incrustation a scraping apparatus was employed, which was the subject of an interesting paper before the Institution of Mechanical Engineers in 1899.

Professor James Campbell Brown brought before the Institution of Civil Engineers, in December 1903, the subject of the various deposits which lessen the carrying capacity of water pipes and culverts, and this communication deserves to be referred to as giving interesting data in regard to the causes which result in the deposits.

CRITICAL VELOCITY.

The phenomenon of the sudden change in the value of "n" at the critical velocity has been investigated by Professor Osborne Reynolds.

It has been generally considered that if a body of water is passing through a pipe in lines or threads parallel to each other, it will continue to do so, provided no change of shape or interruption is caused in the pipe. Professor Osborne Reynolds has, however, shown in a paper published in the *Philosophical Transactions* that beyond a certain velocity (which he terms "critical velocity") the fluid ceases to flow in parallel lines, and suddenly bursts into eddies, a viscous fluid being less liable to form eddies than a non-viscous fluid, and an increase in temperature increasing the tendency to form eddies. This change of a steady motion into an unstable or sinuous motion is of the greatest interest and importance.

No apparent definition had previously been made of the point at which this change of law occurred, or as to the

circumstances which produced the change from steady to unsteady motion, that is, from motion in parallel lines to motion in sinuous or eddying lines.

Professor Reynolds' experiments were made with glass tubes

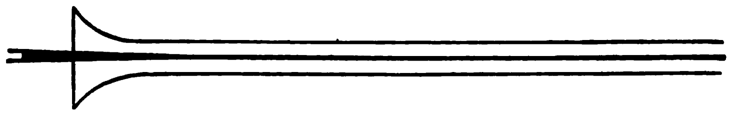


Fig. 19.

about 4 feet 6 inches in length, and 1-inch, ½-inch, ¼-inch diameter, with trumpet-shaped mouths. They were arranged so as to be able to draw water out of a large glass tank in which they were immersed, whilst a streak of coloured water was admitted at the point of inflow of water into the pipe.

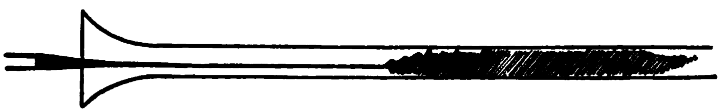


Fig. 20.

Fig. 19 shows the result when the velocities were low, the coloured streak continuing in a straight line. As the velocity was increased, a point was reached when the coloured streak would suddenly break up and become mixed with the clear water, as shown by fig. 20. As the velocity increased, the

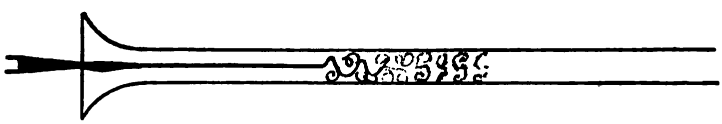


Fig. 21.

point at which the break-up occurred approached the trumpet mouth. By the aid of the electric spark, the eddying or curling appearance of the coloured water was made apparent, as shown in fig. 21. It was found that the velocity at which the junction of eddies occurred was almost exactly in the

inverse ratio of the diameter of the tubes, and that the critical velocity diminished as the temperature rose.

Further experiments were made with water flowing in two straight lead pipes, each 16 feet long and ½-inch and ¼-inch in diameter. Gauge holes were made 10 feet and 15 feet apart in these pipes to measure the head "h" as indicated in fig. 18, p. 14, and the results proved that at lower velocities the head was proportional to the velocity, and that the velocities at which a deviation from the law first occurred were in exact inverse ratio of the diameters of the pipes. Also, that when a velocity equal to the critical velocity multiplied by 1·2 was reached, the pressure did not vary as the square of the velocity, but as 1·722 power of the velocity.

Although the critical velocities in Prof. Reynolds' experiments were found to be in exact inverse ratio of the diameters, the same rule does not hold for pipes of larger diameter. The following Table shows this:—

TABLE OF OBSERVED "CRITICAL VELOCITIES."

Description of Pipe.	Diameter of Pipe in inches.	Temperature in degrees Fahr.	Approximate critical velocity in feet per sec.	Name of Observer.
Lead, ...	0·242	48·2°	1·45	Osborne Reynolds.
,, ...	0·498	46·4°	0·74	,, ,,
,, ...	0·549	?	0·541	Darcy.
Tin, ...	1·06	?	0·322	Dubuat.
Lead, ...	2·5	?	0·22	J. Leslie.
Wrought iron, .	0·48	70°	0·38	Darcy.
,, ,,	0·49	54·5°	1·39	Thrupp.
,, ,,	1·057	52·6°	0·302	Darcy.
Cast iron, . .	15·0	40° to 45°	0·445	Thrupp.

The effect of high pressures upon the viscosity of water is extremely small and differs with the temperature. Mr R. Cohen has made some experiments on the flow of water through a very small tube. He observed the time required for discharging a given quantity of water through the tube with the same working "head," but with the whole apparatus placed under various pressures and temperatures, and he found

that the time required was reduced, as the pressure increased, by the amounts indicated in the following table:—

Pressure in Atmospheres.	300	600	900
Temperature Centigrade.	Reduction of time—per cent.		
1°	3·82	6·28	...
15°	1·49	2·33	2·76
23°	0·76	1·01	...

From these observations it would appear that at about 30° Centigrade (86° Fahr.) the friction of water is not affected by pressure at all, and at higher temperatures the friction would be increased by pressure.

The velocities in these experiments were no doubt below the critical point. At velocities above the critical point (*i.e.*, under ordinary working conditions) the effect of pressure upon the friction would probably be even less than that observed by Mr Cohen.

Water in entering a pipe is subjected to a loss of pressure corresponding to the head required to produce the velocity at which it moves along the pipe. The loss of head can never be less than $\frac{v^2}{2g}$; but it may be more if the entrance to the pipe is not bell-mouthed or tapered. If, for instance, the entrance is square-edged, as in the orifice, fig. 10, p. 8, the loss will be $\frac{v^2}{2g \times \cdot 62}$ or $1{\cdot}6 \times \frac{v^2}{2g}$. This will represent the loss in the case of water entering the square-edged ports of an engine slide valve.

If the mouthpiece is as shown by fig. 13, p. 9, the loss would be only $1{\cdot}01\,\frac{v^2}{2g}$ to $1{\cdot}04\,\frac{v^2}{2g}$.

In the case of a sudden change of diameter in a pipe, as in fig. 22, with a square edge at the mouth of the small pipe, if v is the velocity in the large pipe, and V that in the

small pipe, the loss due to the change of velocity will be $1{\cdot}6\frac{(V-v)^2}{2g}$.

With a gradual reduction of diameter the loss may be reduced to $1{\cdot}01\ \frac{(V-v)^2}{2g}$.

Taking the flow in the other direction there should be a rise of pressure, theoretically; and if the enlargement is gradual

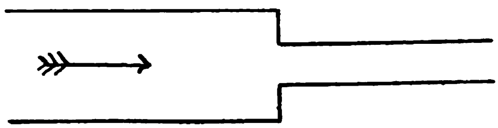


Fig. 22.

with an angle of divergence similar to that of the mouthpiece to orifice on fig. 11, p. 9, it is found that a rise of pressure actually does take place. This was observed by Venturi, and may be illustrated by a pipe having gradual changes in diameter, as in fig. 23; which shows that the water does not rise in the branches up to the line of the hydraulic gradient indicated by the gauges fixed at the wide parts, but falls

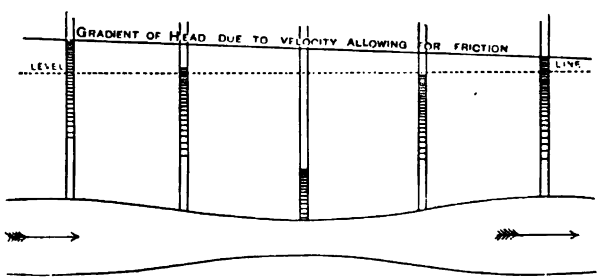


Fig. 23.

rapidly where the pipe is contracted, and rises again as it is diverged, the maximum depression representing the head due to the increase in the velocity of the water in passing from the widest to the narrowest part of the pipe. This principle is utilised to measure the flow of fluids by a Venturi meter hereafter described.

ON PIPES.

6.

$\frac{T-50}{600}\Big)$

5 feet per second

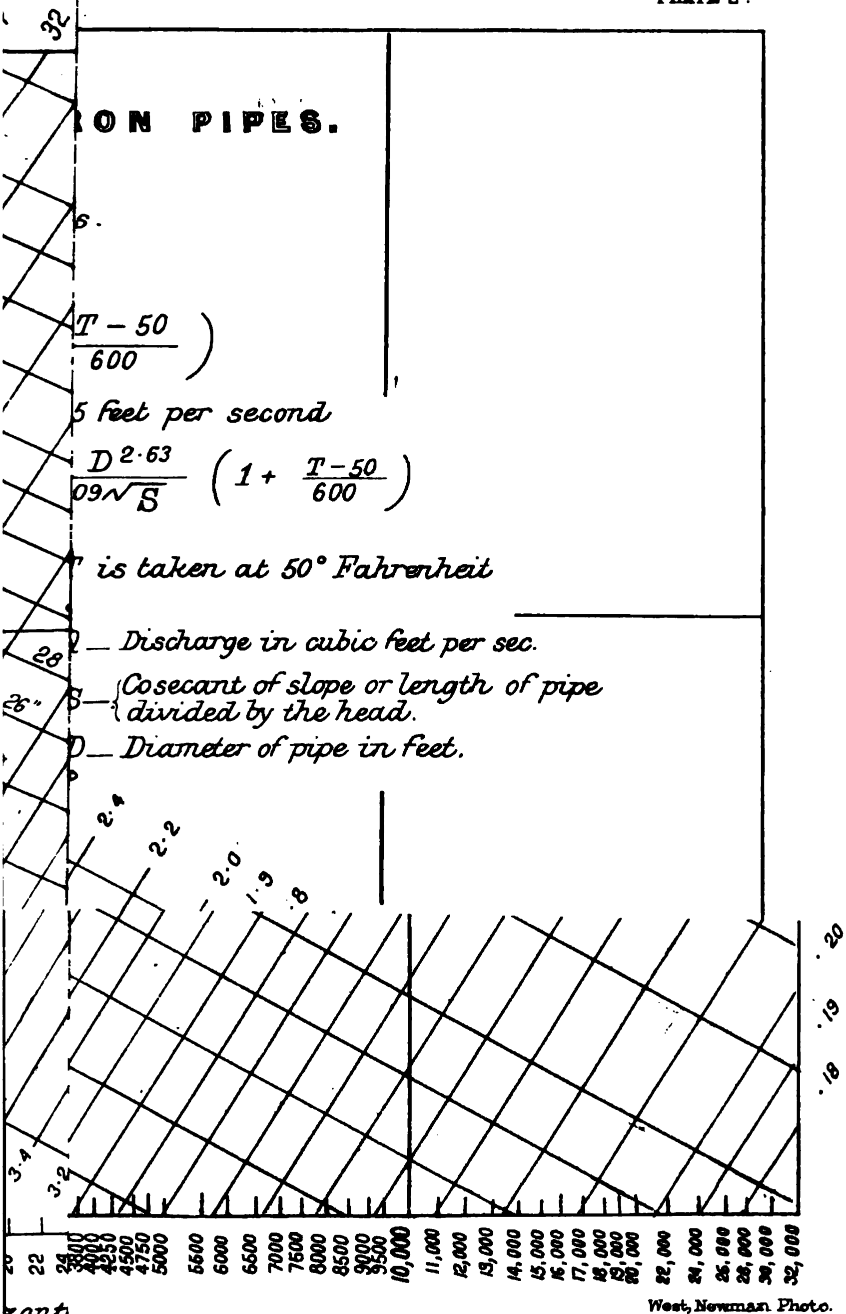
$$\frac{D^{2\cdot63}}{09\sqrt{S}}\left(1+\frac{T-50}{600}\right)$$

T is taken at 50° Fahrenheit

Q — Discharge in cubic feet per sec.

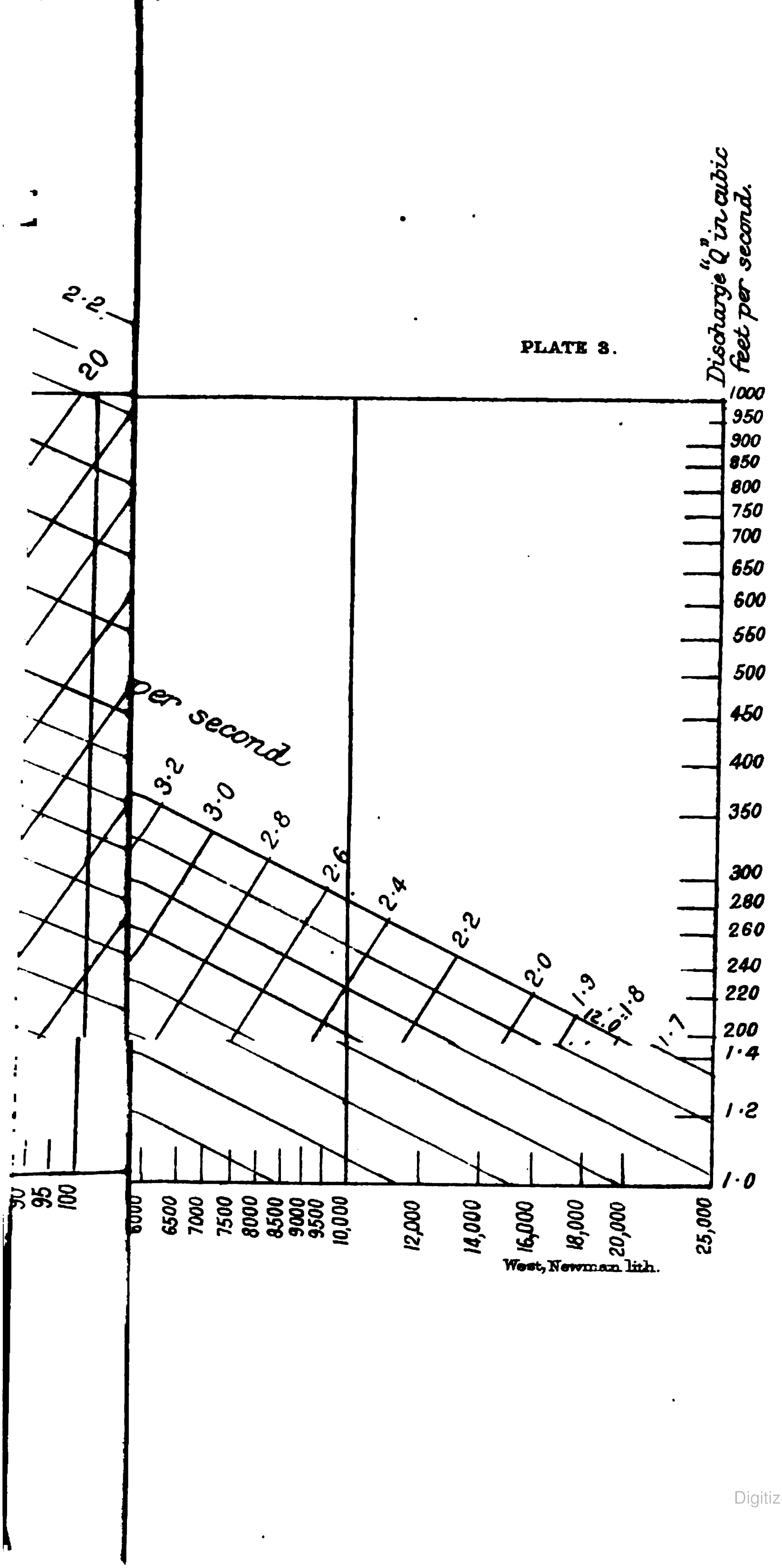
S — {Cosecant of slope or length of pipe divided by the head.

D — Diameter of pipe in feet.



West, Newman Photo.

PLATE 3.



West, Newman lith.

A sudden enlargement in a pipe does not permit the water to raise the pressure in reducing its velocity, as eddies are set up which absorb the whole of the kinetic energy in friction instead of converting it into pressure energy.

A similar loss of power occurs when flowing water passes round a sharp bend or angle, or when it is subjected to any sudden change of the direction of its movement. In flowing round easy bends in pipes there is practically no loss from this cause, but with sharp bends or elbows the loss may be anything up to about $\frac{v^2}{g}$.

These facts point to the necessity of avoiding, as far as possible, all sharp-edged inlets to ports, and also sharp angles and bends. The best results will be obtained when water passages are designed so as to make all the changes of direction and velocity as gradual as possible.

Plates 1, 2, and 3 show the gradients, discharges, and velocities in various sized pipes and circular culverts, and also the velocities for various values of "R" in equations (1) and (3) on pp. 15 and 16. The horizontal scale represents the logarithms of "S," and the vertical scale the logarithms of "Q."

One set of sloping lines refers to particular sizes of pipes or values of "R," and the other set of sloping lines refers to particular velocities. The advantages of this form of diagram are that the lines are generally straight instead of curved, and the results can be read off with exactly the same degree of accuracy from all parts of the diagram, which covers a range of conditions far greater than could be represented in the same space if the natural numbers were plotted.

The natural numbers are written against the lines representing their logarithms, on the vertical and horizontal scales.

Example.—On Plate 1 the spot marked x gives the following coincident values of the various factors:—

$S = 113$ Q (discharge of a pipe) $=$ ·0395 cubic ft. per sec.
$v = 1{\cdot}9$ ft. per sec.
$D =$ ·166 ft. $=$ 2 ins. diameter.

The diagrams all refer to a temperature of 50° F. For accurate results at other temperatures multiply v or Q by $\left(1 + \frac{T - 50}{K}\right)$.

In the *Transactions of the American Society of Engineers* Mr Weston gives the results of some useful experiments which he made to ascertain the effect produced by the sudden closing of valves against water flowing in pipes. Lines of pipes from 1 inch to 6 inches in diameter were laid above ground, and an air-vessel was provided which could be connected or disconnected as required. The supply was drawn from a 24-inch main by a 6-inch pipe. The average static pressure in the pipe was 70 lbs. per square inch. In the first series of experiments the water flowed through lengths of pipes of different diameters thus:—111 feet of 6-inch pipe, 58 feet of 2-inch pipe, and 99 feet of 1½-inch pipe, to a 1-inch outlet pipe, with a ¼-inch orifice. In this case the velocity was 0·15 of a foot per second in the 6-inch pipe, and 5·36 feet in the 1-inch pipe. Upon closing the orifice (which was effected in 0·16 of a second) the force of the ram in lbs. per square inch was 129·2 lbs. in the 1-inch pipe, 127 lbs. in the 1½-inch pipe, and 14·5 in the 6-inch pipe. At the dead end of a separate 2½-inch branch-pipe (leading out of the 6-inch pipe at a distance of 300 feet) the force of the ram was 18·8 lbs. With orifices of $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, and $\frac{5}{16}$ of an inch, and with velocities of 1·06, 2·57, 5·36, and 6·75 feet per second, the rams in the 1-inch pipe exerted a force respectively of 26·9, 72·8, 129·3, and 158·7 lbs. per square inch. In the 6-inch pipe, with ¼-inch and ½-inch orifices, and with velocities of 0·15 foot and 0·53 foot per second, the rams exerted a force of 14·5 and 51·7 lbs.

Mr Weston made another series of experiments on an extension of the 6-inch pipe, comprising 182 feet of 6-inch pipe, 66 feet of 4-inch pipe, 3½ feet of 2½-inch pipe, 1 foot of 2-inch pipe, 6½ feet of 1½-inch pipe, and 6 feet of 1-inch pipe. With the ¼-inch orifice, and with a flow varying from 0·15 of a foot to 5·39 feet per second in the 6-inch and 1-inch pipes re-

spectively, the ram exerted a force of 4·8 lbs. in the former, and of 66·7 in the latter. In the 1-inch pipe, with orifices of from $\frac{1}{8}$-inch to $\frac{1}{2}$-inch, the force of the ram increased from 15 lbs. to 177·5 lbs. per square inch. In the $2\frac{1}{2}$-inch pipe the force of the ram was 22·2 lbs. with a $\frac{1}{4}$-inch orifice, and 183 lbs. with a 1-inch orifice. This latter was reduced to 106 lbs. when the pipes were in connection with the air-vessel. In 6-inch pipes the ram (with a $\frac{1}{4}$-inch orifice) exerted a force of 4·8 lbs., and with the 1-inch pipe 80·1 lbs. The latter was reduced to 65·6 lbs. when the air-vessel was connected.

THE ACCUMULATOR.

Lord Armstrong devised the accumulator as a means of obtaining pressure on a column of water by a weight instead of by elevation (Plate 4). This pressure is obtained by pumping water into a cylinder containing a ram, the top of which is loaded, either with weights or by a weighted case attached to a crosshead connected with the ram. The weights, or weighted case, can be adjusted to give any required pressure to the water, which is transmitted through mains to the various appliances actuated by the water under pressure. A stop valve enables the water to be cut off. When the ram has risen to the top of the stroke (and the cylinder is full of water under pressure) it stops the engine by means of a chain connecting with the steam throttle valve of the engine, and water ceases to be pumped into the accumulator. When the ram falls (owing to the abstraction of water from the cylinder), the steam throttle valve is opened, the engine works again, and water is pumped into the accumulator.

The pressure that has been adopted for transmission through mains, in order to work ordinary hydraulic machines, is about 700 lbs. per square inch. This is found to be a convenient working pressure, both as regards the size and proportions of the working parts and the tightness of joints and valves.

The best way of jointing hydraulic pipes has been the subject of much practical experiment. A guttapercha ring has been adopted as the best means of preserving the joint water-tight. Where hydraulic mains are exposed to heat the guttapercha ring will not answer, and leather is employed instead.

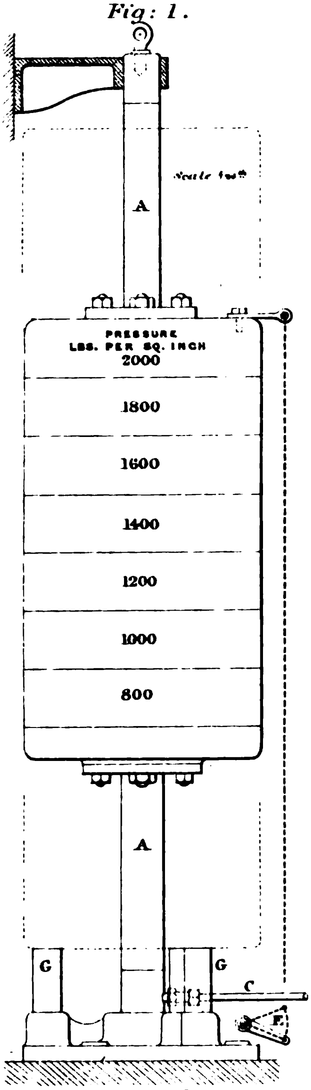
Mr Ellington has designed a modified form of this joint by putting a projection on the pipe beyond the flange, the spigot and faucet being formed on this projection. The effect is to increase the depth and the strength of the flange, without an increase of its section at the junction between the flange and the pipe.

By means of an accumulator an artificial head can be maintained at any part of an hydraulic main. The abstraction of the high-pressure water to actuate hydraulic appliances is practically intermittent. The supply of high-pressure water from the pumping-engine can be continuous. It follows, therefore, that as the transmission of pressure through a water main is practically instantaneous, the intervals (however small) between the time of the production of the power and its utilisation in the appliance enable the pressure to be maintained and the excess to be stored in the accumulator. The variation in the consumption of the power, by reason of the fluctuation in the working of the machines, is at once adjusted by the accumulator, which both serves to store up the excess of power delivered to the mains from the engines, and also to maintain the pressure in the mains. By this means power is transmitted without practical loss in hydraulic mains. An experiment is recorded as having been carried out on the 6-inch mains of the London Hydraulic Power Company when the main valves were set so that two accumulators differently loaded (the difference being 20 feet head) were at the ends of a circuit of 5 miles. The lighter accumulator was lowered and shut off, the heavier remaining at the top of its stroke. The lighter accumulator was then turned on, and it was raised by the heavier one.

ACCUMULATOR.

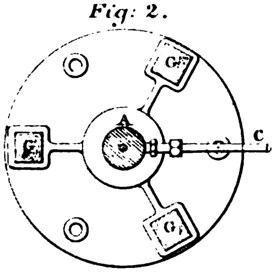
PLATE. 4.

Fig: 1.



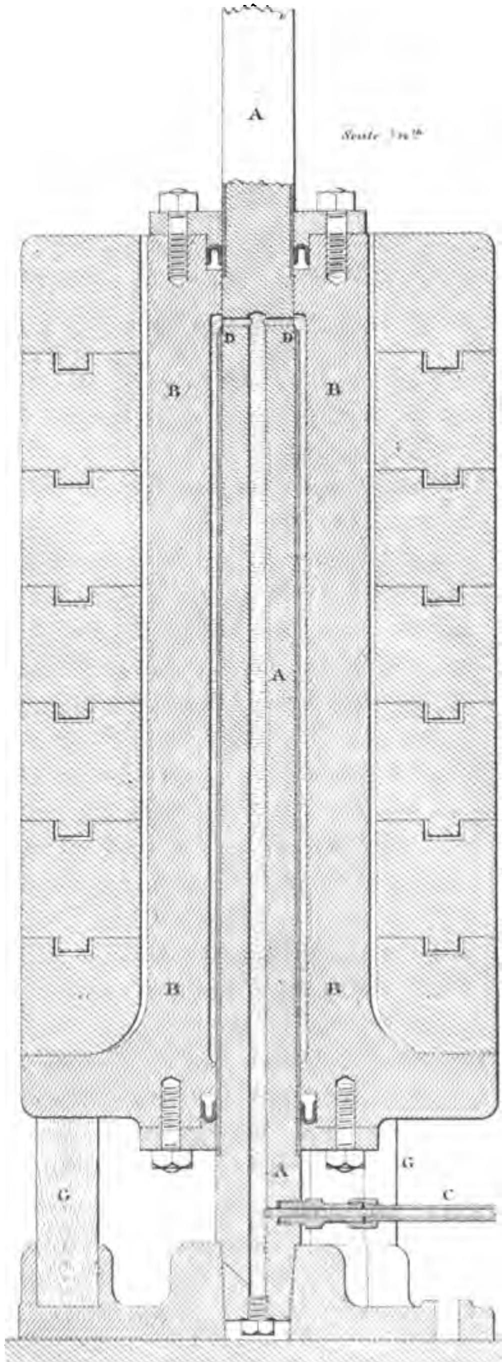
ELEVATION.

Fig: 2.



PLAN AT BOTTOM.

Fig: 3.



VERTICAL SECTION.

The amount of energy which is stored up in an accumulator when the ram is at the top of the stroke is ascertained in the following way:—Taking a 12-inch accumulator having a stroke of 22 feet, and working at a pressure of 750 lbs. per square inch:—

Area of 12-inch ram = 113·097 square inches.

Energy stored = 113·097 × 750 × 22 = 1,866,150 foot-lbs.

$$\frac{1,866,150}{33,000} = 56 \cdot 5 \text{ horse-power acting for one minute.}$$

This store of power is capable of being given out as required either quickly or slowly, according to the working of the appliances.

Mr Andrew Betts Brown has devised an accumulator by applying steam to one side of a piston which acts upon a water ram. This accumulator consists of a large steam cylinder 36 inches in diameter, fitted with a piston and a piston rod, which forms the ram of a hydraulic cylinder, having $\frac{1}{15}$th the area of the steam cylinder. A steam pressure of 50 lbs. per square inch, therefore, gives a water pressure of 750 lbs. per square inch in the hydraulic cylinder (less the amount of friction). Steam is admitted to the top of the accumulator cylinder from the ordinary donkey boiler, or the main boilers. The pumping-engines are supplied by a branch from the opposite side of the cylinder, and deliver the water from their pumps into the hydraulic cylinder. The bottom of the accumulator-cylinder is open constantly to the exhaust. When steam is turned on to the accumulator, the engines start, at the same time pumping up the hydraulic ram, and they continue working until the steam piston rises high enough to close the steam-pipe orifice. The engines then stop, but when water is drawn from the accumulator by the action of the hydraulic machinery, the steam-piston descends, maintaining the pressure of 750 lbs. per square inch upon the water; at the same time, by opening the steam-pipe it starts the engine again, by which the accumulator is replenished.

An accumulator was designed by the late Mr Tweddell to

meet the variation of demand for high-pressure water, such as arises when only one appliance is at work in a system of hydraulic pipes supplying numerous shop tools. This is shown by Plate 4, from the *Proceedings of the Institution of Mechanical Engineers.* The ram or spindle A of this accumulator is fixed, and acts as a guide, whilst the cylinder B slides upon it, and is loaded with the weight necessary for giving the required pressure to the water. The water is pumped in at the bottom at C, and fills up the annular space surrounding the spindle. The whole weight has to be lifted by the water acting only on the shoulder D, which is made by a brass bush $\frac{1}{2}$ inch thick all round the spindle. A compact arrangement is thus gained, and any required cubic capacity is obtainable by lengthening the stroke. The accumulator is supplied by two pumps, each $1\frac{3}{8}$ inch diameter and $3\frac{1}{2}$ inches stroke, running at about 100 to 120 revolutions per minute. When the loaded cylinder B reaches the top of its stroke, it is made to close the suction cock E of the pumps, thus stopping the supply of water. When it is desired to put in a new packing-leather at the bottom, the weighted cylinder is let down to rest upon blocks placed on the wood chocks G at the bottom, and the spindle is drawn up out of its tapered seat by the eye-bolt at the top. To renew the top leather, the bracket holding the top end of the spindle has to be removed. This accumulator (having only a small area) falls quickly when the water is withdrawn, thus producing a combined blow and squeeze, which is of great advantage in hydraulic rivetting.

A means of intensifying pressure is shown by fig. 24 (from the *Proceedings of the Institution of Mechanical Engineers*). A pipe A conveys low pressure water into the cylinder B. The pressure on the piston C acts upon the smaller ram D, and gives an increased pressure to the water in the second cylinder E, in proportion to the relative areas of the piston C and the ram D. In the illustration, the piston is 19 inches and the ram $3\frac{3}{4}$ inches in diameter. A pressure of 60 lbs. per square inch on the piston gives 1540 lbs. per square inch on the ram.

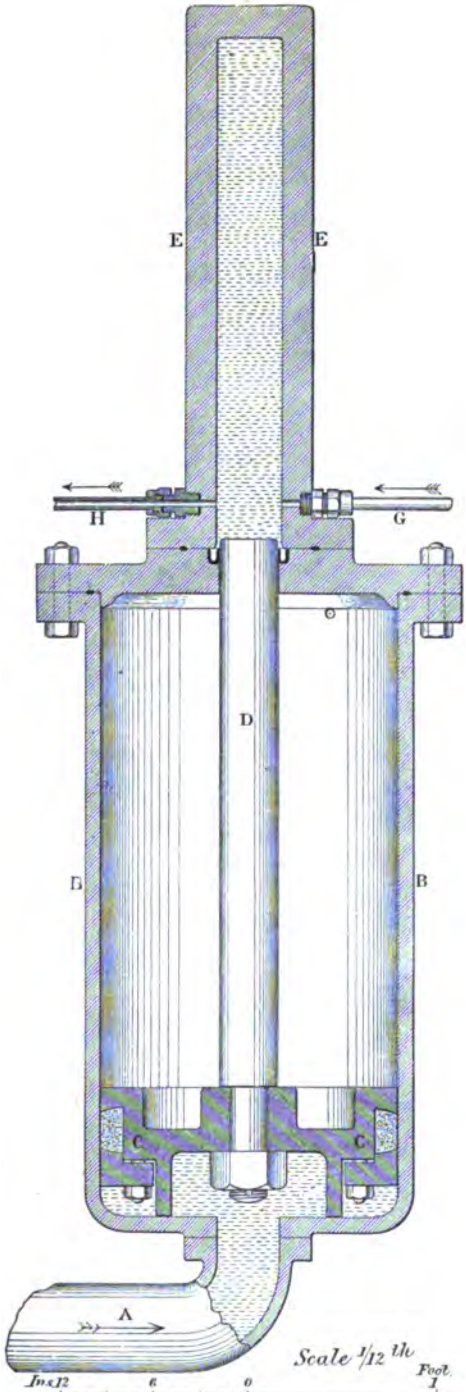


Fig. 24.—Intensifying Accumulator.

The water from the pumps enters through the inlet G, and passes out at H to the machine to be worked by it. No water is consumed from the low-pressure cylinder, but it is simply driven back by the force pumps into the low-pressure accumulator or mains.

The loss of useful effect between the pumps and a properly packed accumulator is but trifling. Experiments carefully made by Mr Tweddell are recorded of the working of two pumps delivering water into an accumulator. The exact height that the ram was raised by the strokes of the pump was registered. With one pump working, 1694 cubic inches was the theoretical delivery of the pump for 20 strokes, and 1614 cubic inches was the actual quantity pumped into the accumulator, showing a loss of only $4\frac{3}{4}$ per cent. With both pumps working, the corresponding quantities (for 20 strokes) were 3388 cubic inches, and 3278 cubic inches, showing a loss of only $3\frac{1}{4}$ per cent. It was noticed in these experiments that 1250 lbs. per square inch was the ascending pressure in the accumulator, and 1225 lbs. per square inch was the descending pressure. In ascending, the friction had to be overcome by the pump in addition to lifting the load, and in descending, the friction had to be overcome by the load itself; the amount of the friction will therefore be half the difference of pressure in the two cases, or $12\frac{1}{2}$ lbs. per square inch, which is equivalent to 1 per cent. of the power.

Messrs Clark & Standfield have arranged a differential accumulator for working hydraulic lifting-presses. In their accumulator the dead-weight of the machinery which has to be raised and lowered is constantly balanced, so that only a small additional power is required to give it motion. Three accumulator-rams, or plungers, are usually employed, two of which are of such dimensions as to produce a pressure on the ram of the hydraulic press exactly sufficient to balance the dead-weight of the machinery carried by it. In this condition the accumulator and the hydraulic press are in equilibrium, and a very small increase or decrease of pressure suffices to

cause the hydraulic ram to ascend or descend, as the case may be. An extra load is then put on the accumulator sufficient to cause it to descend, and to raise the hydraulic ram with any desired load upon it. The third plunger is placed centrally under the head of the accumulator, and the pipes communicate with the two outer plungers so that all three can be connected at will. When the accumulator is down, and the ram is elevated (as just described), then if the communication is opened between the three plungers, the weight of the accumulator, which was at first supported by two plungers, being now supported by three, the pressure on the water is diminished, and consequently the accumulator ascends and descends. In order to raise it again it is only necessary to allow the water to escape from the central ram, when the whole weight becomes supported on the two plungers as before, and the pressure is consequently increased and the ram again ascends. A small pump is employed to keep the accumulator charged.

In order still further to diminish the loss of power entailed by hydraulic rams when raising and lowering heavy weights, Messrs Clark & Standfield compensate for the varying immersion of the ram. When a ram is raised in the ordinary manner, it is evident that, as it ascends out of the water into the air, it increases in weight, and its balancing power diminishes by an amount which is equal to the weight of a column of water of its own bulk. Similarly, as the plunger of an accumulator descends, it loses a weight equal to the bulk of a column of water which it displaces, and both of these actions concur to diminish the power of the machine more and more as it approaches the full extent of its stroke. To obviate this, the load on the accumulator is increased, as its plunger descends, by a weight of water sufficient to compensate for the varying immersion of the plunger and of the ram of the press. By this means the dead-weight of the machine itself is counterpoised in every position, and the only power required to work the machine is that which is requisite to raise the load itself

and to overcome friction. By the same means increased power is given at the end of the stroke, by adding to the load a greater weight of water than is required for compensating for the varying immersion of the rams and plungers. Conversely, decreased power may be given at the end of the stroke by causing weighted tanks or vessels (which form the load of the accumulator) to descend into water.

Where it is desirable that two or more rams should ascend synchronously through equal distances (as, for instance, in the two ends of a bridge or canal lift, or in raising guns) two or more plungers are combined into a group beneath one accumulator, so that as the plungers descend, all the rams ascend through uniform distances. In order to cause all four corners of a bridge or other moving apparatus (which is supported by presses at its two ends) to ascend or descend in a horizontal position, means are provided for allowing an escape of water from beneath either of the rams, if from any cause one of them should become elevated above the other.

Many years ago, Lord Armstrong arranged, for the Tyne Commissioners, an air accumulator to work at about 250 lbs. to the square inch. He had some hydraulic cranes put on board a screw hopper barge, used for discharging ballast from vessels lying in the pool of the river, and taking it for deposition out to sea. These cranes lifted 2 tons, and were able to discharge 60 tons an hour. They had hydraulic lifting, turning, and traversing motion applied to them. As it was not considered practicable to introduce an accumulator on this small barge, a cast-iron air vessel was adopted to work at 1000 lbs. on the square inch. Some difficulty was experienced in the first instance in working the air pump with this high pressure, but by introducing a small stream of water with the air on the suction side, and by allowing the water to fill up the spaces between the ram and the valve, not only was all difficulty overcome, but even a higher air pressure was able to be used. Before this small stream of water was employed a certain amount of air remained in the cylinder, and as this air

was not forced out by the plunger, it prevented the full amount of air at the end of the stroke from being sucked into the cylinder for the next stroke. The introduction of a small quantity of water caused this space to be taken up by the water, and so that difficulty was overcome. Owing to the air getting mixed with the water, a cream was formed, which was obviated by the application of water in the small air-pump.

At the outset of the employment of water-power it was feared that the water in the pipes and machinery might freeze. This, however, has been found not to be a difficulty where well-known precautions are taken. The working parts should, where possible, be placed under ground, or should be cased in, if they are above ground. In frosty weather the water should be run out of all valves and cylinders which cannot be cased in, and protected, as soon as the working of the machines ceases. A very small gas jet or lamp placed near the unprotected parts will prevent freezing.

Experiments have shown that a mixture of glycerine and water prevents the effects of frost to a temperature as low as 16° Fahr., provided the glycerine has a specific gravity of 1·125, and that it is mixed in the proportion of one part of glycerine by weight to four parts of water. Where water is scarce and is used over again in the machines (by returning the exhaust water from the machines to a reservoir), such addition of glycerine is more easily resorted to. Where only moderate risks of frost have to be dealt with, the proportion of 1 gallon of glycerine to 300 gallons of water proves effectual. If the water is at a high pressure, such as 1500 lbs. to the square inch, it is less liable to freeze than when it is at a low pressure.

THE FLOW OF SOLIDS.

Hydraulic forging presses have revolutionised the treatment of large masses of iron and steel, by enabling immense pressures to be brought to bear on molten metal plates or masses of iron

and steel. By means of fluid compression ingots are produced of a soundness which was hitherto impossible of accomplishment, and by hydraulic pressure masses of metal can be squeezed into required shapes far better than by blows from a steam hammer.

The employment, in recent years, of iron in increasingly large masses has involved the consideration of how the continuity of the fibre can be maintained, and what the conditions are which have to be observed in order to prevent break of continuity, or a diminution of the calculated strength of the mass. The investigations of the late M. Tresca (recorded in the *Proceedings of the Institution of Mechanical Engineers*, 1867 and 1878) have thrown much light on the subject, and are of practical value in regard to forging, under a pressure or squeeze, instead of by a blow. M. Tresca applied the expression "the flow of solids" to his investigations, and the singular facts which he established indicated that an entirely new branch of observation had been opened out, to which M. de Saint Venant gave the name of "plastico-dynamics." Fig. 25 shows the result of applying pressure to discs of lead. Ten discs of lead (each 0·12 of an inch thick, and 3·94 inches diameter) were subjected to pressure, by which the lead was forced to flow through a concentric circular orifice 1·18 inch diameter in the movable disc C C placed at the bottom of a cylinder, a plunger in which exerts the pressure.

The dotted lines in the cylinder show the original positions of the discs, the upper surface being at D D. On applying pressure the jet reached 7·87 inches, which is the position in the figure. An examination of the jet proved that the layers remained flat back from the central jet, and that they bent over from this area so as to flow into the jet simultaneously, the external surface being formed of the bottom disc, which has assumed the shape of a cylindrical covering. The other layers form separate tubes concentric with the jet, all being closed at the outer end by a cap formed of the central part of the disc.

A further experiment with a cylindrical block having a

smaller height, compared with the diameter of the orifice, gave a result as shown on figs. 26 and 27.

The orifice in these two cases was 1·58 inch diameter, and each disc was 0·12 of an inch thick. D D (as before) was the original position of the layers. It is interesting to notice that the diameter of the jet is not that of the full diameter of the orifice, but a "vena contracta" has been formed, such as occurs

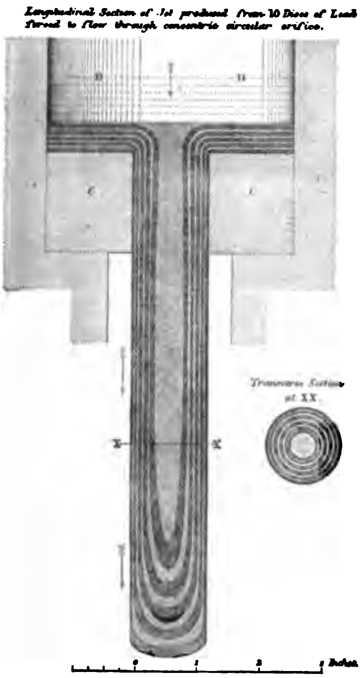
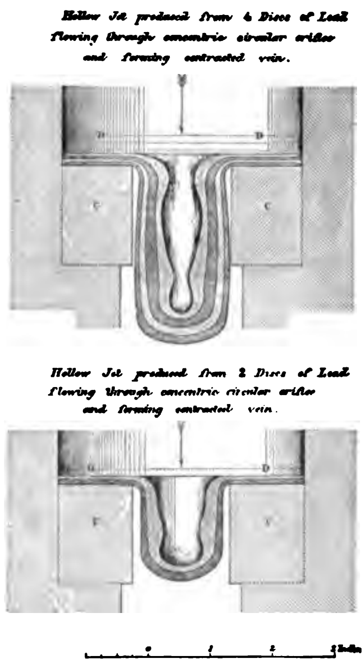


Fig. 25.



Figs. 26 and 27.

in the flow of liquids. In further experiments the undulations which were observed in the metal corresponded with the relative motions of the particles of a similar vein of fluid.

Many other metals besides lead were subjected to pressure through an orifice, and the general conclusion arrived at from them was, that the particles of solid bodies flow under pressure similarly to liquids. Any alteration in the shape of the orifice, from the circular to the polygonal, or eccentric,

produced torsional movements of the metal corresponding to the gyratory movements which occur in the flow of a liquid through an orifice, which is not placed symmetrically to the sides of the vessel containing it. When the metal was pressed through more than one orifice in the die, it was observed that the jets nearest the centre were rather larger than those near to the sides of the cylinder, the lesser effect being due to the friction of the sides. This difference in pressure on different parts of a solid mass explains the displacements that take place in the interior of the mass.

The experiments proved that the pressures exerted on the surface of a solid body are transmitted throughout the whole interior of its mass, and tend to produce in it a flow which is propagated from particle to particle, and which necessarily develops itself in the direction where the resistances to the flow are the least; also that the pressures thus transmitted determine in a fixed order the changes of form at each point. Further, these changes of form are attended by a loss of pressure between one point and another, similar to, but even greater than, that in the case of the flow of liquids.

In the processes of rolling and forging iron the observations of M. Tresca have a practical value, as indicating the necessity for the application of a pressure or blow sufficiently powerful to reach the interior of the mass in order to enable the metal to flow, and its fibrous continuity to be preserved.

HYDRAULIC PRESSES.

The Bramah Press is a practical application of the law of the equal transmissibility of fluid pressure, by which a force that is exerted by a small ram on one unit of water-surface is capable of being exerted over any number of units of water-surface in direct communication with the cylinder which contains the water that receives the initial pressure.

In presses of small diameter the calculation of the thickness, and the proportioning of the metal round the orifice admitting the water, have been matters of no difficulty, but the gradual increase in the size of presses to meet the development of the use of hydraulic power has involved new arrangements of construction.

In determining the thickness of hydraulic cylinders, where the thickness of metal is not small as compared to the radius, the conditions of strain on the inner and outer radius of the metal are not the same, so that it must not be assumed that the thickness can be increased in direct proportion to the strain.

For thin cast-iron cylinders and water pipes—

P = pressure in lbs. per square inch.
R = internal radius in inches.
T = thickness in metal.
C = coefficient for cohesive strength of the metal.

Then

$$\frac{T}{R} = \frac{P}{C}$$

When C = 16,500 lbs. for the bursting tension.
= 5,500 lbs. for the proof tension.
= 2,750 lbs. for the working tension.

The cylinders of presses that are subject to great strain are now best made of steel that has been subject to fluid compression, by which a more uniform molecular structure, strength, and ductility is preserved throughout the whole body of metal than can be obtained otherwise. The usual thicknesses are for a 14-inch press, 2¾ inches, with a maximum tensile strain of 9 tons on the inner surface when worked at a pressure of 2¾ tons to the square inch. An 18-inch press would have a thickness of 3¼ inches, the usual working pressure not being more than 2½ tons per square inch. The tensile strain on the inner surface of the press is determined by the formula deduced by Hooke.

$$P = p \cdot \frac{R^2 + r^2}{R^2 - r^2}$$

Where P = the tensile strain per square inch on the inner layer,

p = pressure per square inch on the cylinder internally.
R = the outer radius.
r = the inner radius.

Experiments that were made to determine the method of constructing the presses for canal lifts are described elsewhere on pp. 52 to 58.

The employment of hydraulic pressure for the manufacture of steel guns was referred to by Major Mackinlay, R.A., in a paper which he read at the Royal United Service Institution in 1885. The construction of a steel gun by the aid of hydraulic presses engaged Sir Joseph Whitworth's attention, and he applied to this purpose the principle which he had successfully used to manufacture hollow propeller shafts. In this case the solid cylindrical ingot from which the shaft is to be made is first bored and converted into a hollow cylinder. It is then heated, and a hollow steel mandrel of smaller diameter than the interior is placed inside it, and the action of hydraulic pressure is brought to bear upon the external longitudinal surface of the cylinder. The press squeezes the metal against the mandrel within (which is kept cool by water flowing through it), the cylinder being turned over during the operation, so that it is evenly pressed throughout. The effect of this pressing is to bring the internal diameter of the cylinder to that of the mandrel, and at the same time the length of the cylinder is increased. By reheating the cylinder, and repeating the process of pressing with smaller mandrels, the final proportions of the propeller shaft are obtained. A similar process is employed in making steel guns and presses. The ingot is cut into thick rings which are squeezed in presses round mandrels, as already described.

Since the successful application of the forging press by Sir J. Whitworth, the demand for large forgings of every description has compelled its adoption by firms who desired to acquire, or to maintain, a position in the front rank of makers

of the heavier class of steel forgings. The size of forgings has progressively increased, and to deal with them efficiently, larger and larger presses have been, and are being, constructed. The most recent are capable of turning out any variety of forgings, besides plain round shafts, and at a minimum of cost in labour.

Up to a certain size the single-cylinder system of construction is allowable, but in the more powerful presses it becomes necessary to substitute double cylinders. The latter system enables the weight and magnitude of the individual parts to be brought within practicable limits, besides which the width of the entablature is reduced to a minimum. The reduction of width is an advantage, inasmuch as it allows the sling chains of the crane to approach so much nearer to the anvil, thus giving greater command over the ingot without having to use excessively heavy balance weights on the porter bar.

CYCLONE HYDRAULIC BALING PRESS.

The packing of textile or fibrous material so as to minimise the risk of fire on ship board has received much attention at the hands of those engaged in the construction of presses, and one form, which is known as the Watson-Fawcett "Cyclone Press," and is manufactured by Messrs Fawcett, Preston & Company, Limited, of Liverpool, deserves notice. The special feature of this press consists in combining fixed or revolving filling boxes with a revolver having several chambers by which several bales are being formed simultaneously. Illustrations of this type of press are given on Plate 5. Fig. 1 shows a press with a three-chamber revolver and one fixed filling box, and fig. 2 shows one with three chambers in the revolver and two revolving filling boxes. Selecting the press shown by fig. 2 the following description will explain the method of working:—

The press is fitted with two upper rams of large diameter

and very short stroke, and two lower rams of small diameter and very long stroke. A revolver, having three chambers, is fitted on one of the main columns, and revolves thereon from the position over the long stroke or bottom rams to that over the short stroke or top rams; two revolving filling boxes are fitted on the outer or long columns and revolve around it from the position over the long stroke or bottom rams to the outside position where the filling takes place. The fact that the revolver admits simultaneously of one bale being in one chamber over the large rams, of a second bale being in a second chamber over the small rams, and of a third bale being in the third chamber out of the press and in the lashing position, accounts for the large out-turn of which the "Cyclone" press is capable. The working of the press is as follows:—A bale is first pressed up into the A chamber of the revolver, which is then turned a third of a revolution, placing the A chamber with its bale in waiting position, where the preliminary lashing is done. The chamber B is then over the lower rams, and a full box being turned into position over them, a bale is compressed into the B chamber of the revolver, which is again turned the third of a revolution, placing the chamber A with its bale over the upper rams, the B chamber with its bale in the waiting position to receive the preliminary lashing, and the C chamber over the lower rams.

The regular action of the press now commences. The inlet valve is opened to the upper rams which fully compress the bale in the A chamber of the revolver. The hoops are made fast in the usual way, the outlet valve is opened, the rams fall, and the bale is turned out of the press. When the pumps finish the pressure on these rams, finally compressing the bale in the chamber A, the inlet valve to the lower rams is opened, allowing the water from the pumps to flow into the lower cylinders, raising these rams, and compressing a bale into the C chamber of the revolver. [These lower rams, when near the end of their stroke, are sometimes arranged to withdraw the lock bolt of the main doors by means of a tappet rod fixed to the follower,

which may also be used to stop the rise of these rams when at their top position, by lifting the weighted lever of a relief valve at the bottom of the press]. The doors are then pushed back, and the lower lashing plate is locked to support the bale in the C chamber. All three chambers of the revolver are now ready to be moved round a third of a revolution, which brings the A chamber in position over the lower rams, the B chamber with its bale three-fourths hooped, over the upper rams, and the chamber C in position to receive the preliminary lashing, where it gets its bale three-fourths hooped. The lower lashing plate in the A chamber of the revolver is then allowed to fall on the follower of the lower rams, which is waiting for it at top of the box. The outlet valve of the lower rams is opened, and those rams fall, carrying this lashing plate to the bottom of the box, the stop is withdrawn, and the boxes turn half a revolution, placing a box full of cotton over the lower rams and under the A chamber of the revolver. When the B chamber of the revolver strikes the stop, fixing it in position over the upper rams, the inlet valve to those rams is opened, and the bale in that chamber is fully compressed by the rise of the rams. The inlet valve to the lower rams is then opened, compressing another bale into the A chamber of the revolver; the main doors are then unlocked and pushed back, and the lashing plate locked under the bale. All three chambers are thus again ready to be pushed round. The bale in the chamber B having been hooped and turned out, leaving that end ready to move into position over the lower rams, the bale in the chamber C has received the preliminary hooping, and is ready to move into position over the upper rams, and the A chamber is ready to move with its bale to the position for hooping, and so on.

It will be seen that three bales are under treatment simultaneously, and that the pumps are practically continuously at work pumping into either the lower or the upper cylinders. Thus, at the same moment, a first bale in No. 1 chamber of the revolver is receiving the final pressure from the upper rams; a second bale which has been previously

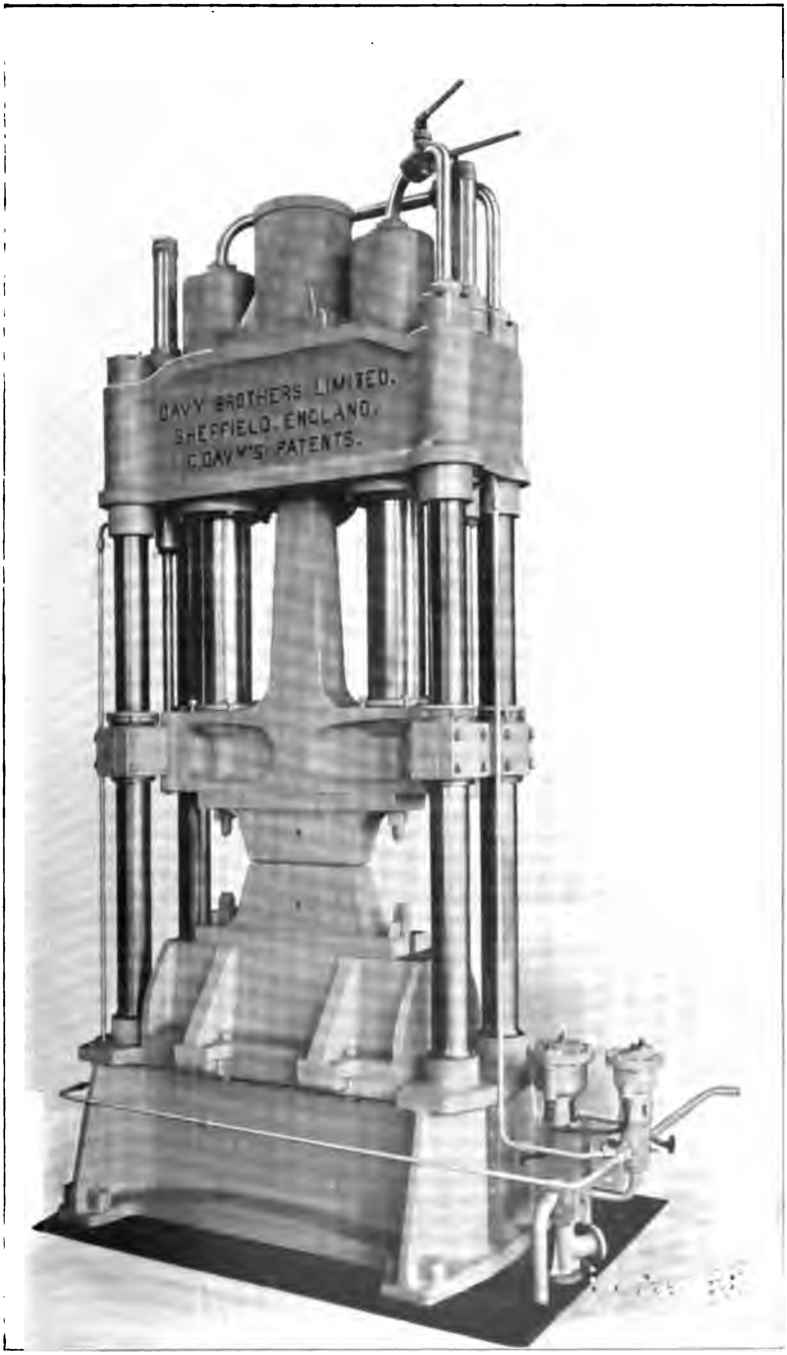
pressed up by the lower rams into No. 2 chamber of the revolver, and moved out from its position above the lower rams, is receiving its preliminary lashing; and material for a third bale is being filled into one of the deep boxes which is at the outside or filling position. The working of the press shown by fig. 1 is the same, with the exception that, having one fixed filling box, the material to be pressed is filled in through the upper space at the doors.

DUPLEX CYLINDER FORGING PRESS.

Plate 6 represents a form of forging press of the duplex type (made by Messrs Davy Brothers of Sheffield) which offers advantages over the single cylinder press. By placing the two cylinders one near each end of the press, both the weight and the width of the entablature can be reduced to a minimum. The reduction of width allows the cranes to approach nearer the centre of the press, thus giving greater command over the ingot without having to use excessively heavy balance weights on the porter bars. By placing the cylinders near to the columns the bending moment on the entablature girders is very moderate compared with that of a press having a cylinder of equal power placed centrally. The difference in favour of the former is as 38 to 100. In effect, the bending stress is divided between the entablature girders and the crosshead or tool-holder, so that the weight of each of the parts in question is not excessively heavy, and for the same width between the columns this construction is lighter than in a single cylinder press.

To ensure the parallelism of the crosshead a shank is attached to it extending upwards into a bored guide fixed centrally over the entablature. The ends are also fitted with guide blocks encircling the columns, the whole forming an inverted T-piece guided at the top of the shank and at the ends of the horizontal member.

The pressure of the rams is transmitted to the crosshead through long spherical-ended thrust rods seated on the cross-



DAVY'S DUPLEX CYLINDER FORGING PRESS.

head and near the tops of the rams, which are made hollow for this purpose. The side strains which arise when the press is in action are thus taken on efficient guiding surfaces, leaving the rams perfectly free from all side stress. With this arrangement of guides no inconvenience is experienced from side strains even if the forging is pressed at a considerable distance from the centre of the anvil, and it follows that both for handiness in working, and for the range of work that can be done, a two cylinder press of this type has advantages over a single cylinder press, in which the side stress has all to be taken on the main ram.

In a single cylinder press it is usual to fit the packing leather to the top of the ram, but in the duplex press a groove is turned in the mouth of each cylinder to receive the packing leathers so that the ram is the surface which works against the packing leather instead of the interior of the cylinder.

The advantage of this is that the rams are always exposed to view, and any scratches that may take place can be seen at once and remedied, whereas if the packing leather is fixed to the top of the ram any grooving that may take place will be on the inside of the cylinder, and this cannot be detected until it destroys the leather. It is also difficult and expensive to rectify any defect on the inside surface of the cylinders, whereas in the case of the rams the surfaces can be fully exposed by lowering the crosshead, and any defect is easily remedied by polishing the rams if occasion requires. The lifting cylinders have a longer stroke than the main rams, so that these latter can be easily lowered down out of the cylinders for changing packing leathers.

PACKING.

For stuffing-boxes for rams, a gasket of hemp, plaited very tight, and well greased, is a very simple and durable packing. After it has become well consolidated the friction is but little, although at first it is considerable. A slight leak serves to

lubricate the packing. Where the packing is exposed to heat, hemp is a more suitable material to employ than leather. When the plaiting is done carelessly, the use of hemp is attended with the objection that portions are liable to be torn off when the gland is first packed and worked, and these pieces are liable to get into the valves. The packing having to be compressed to meet the maximum pressure that the appliance may be worked at, the friction is a constant, although the machine may be working sometimes at a lower pressure, whereas with leather packing the friction varies directly with the pressure, and therefore the loss due to friction under varying pressures is less with leather packing than with hemp.

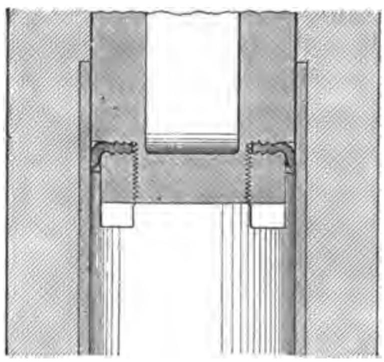


Fig. 28.

Benjamin Hick introduced the use of cupped leathers into presses, and the experience of his descendant, Mr John Hick (referred to hereafter), affords valuable data as to the coefficients of friction with leather packing. A cupped leather forms a self-tightening packing, and is very generally used, although it soon wears out and fails when the cup is not properly supported at the bend (where the greatest friction is). This should be done by the insertion of a ring or bush of brass or gun-metal, which prevents the rapid wearing away of the bend of the leather. It has been found that when the cup has been made with a square, instead of with a rounded, edge, the joint has not been so water-

tight. A form of packing which has been found to answer well in the cylinders of hydraulic capstans is shown in fig. 28.

Where the cup leather is placed in a shallow (instead of a deep) groove, there is not so much need of the support. The leathers are frequently made far too deep, and this leads to their being more liable to crack, and fail. Gutta-percha or india-rubber cups, and brass or lignum vitæ rings, have been used for packing, but on the whole the leather cup is the best. With a view to obviate the inconvenience and delay caused by the failure of a leather packing, "Watson's patent double leathers" are used in some presses. The neck of each cylinder has a provision for two leathers, one below the other, no pressure reaching the upper one until the lower one has worn out or burst. In that event the working of the press is not stopped, as the second leather is brought into use by the attendant screwing down a valve while the press is working.

As the efficiency of hydraulic machines largely depends on proper packing, too much care cannot be taken in seeing that good leather only is used, and that the moulding of the cups is well done. The leather employed for making the cups ought to be of good and close quality, having had oil or tallow well rubbed into it after tanning. Before pressing the leather in moulds, to make the cup, it should be soaked in water till quite pliable, and after being forced into the mould it should be left for about twelve hours, then taken out, trimmed, allowed to dry, and afterwards replaced in the mould for an hour or two. It can then be removed and dressed to the required shape. The presence of gritty matter in the water injuriously affects leather packing, and involves frequent changing of the cups. Where dirty gritty water has to be used, the leathers wear away very rapidly when the cups are not kept constantly under pressure. If the pressure is taken off hydraulic machines by the accumulator resting on its bed, the water gets between the leather and the ram; and as soon as the accumulator rises off its bed, and the pressure comes on, a little gritty water passes between the leather and the ram, and causes the wear on the

packing. An expedient which has been successfully adopted consists in putting a relief valve on the pipe that delivers water to the accumulator from the pumps, and in leaving the suction valve always open. When the relief valve is lifted, at the top of the stroke of the accumulator ram, the pumps being always full of water, the accumulator cannot drop on to its bed. The pressure is in this way constantly kept on the leather, preventing leakage, and at the same time remedying the wear and tear of the packing. The employment of a gun-metal lining to the cylinder has been found to add to the life of the leather packing. The loss occasioned by friction in pumping into an accumulator having a well-packed stuffing-box (hemp packing being used) has been found to range from 3 to 8 per cent. at 700 lbs. pressure. The difference of pressure during the rise and fall of the accumulator represents from 1 to 2 per cent. of the power.

Experiments made by Mr John Hick show that friction increases directly with pressure. With leather packing for rams of different diameters, if the pressure per unit of area be the same, friction varies directly as the diameters, or as the square roots of the gross loads. Neither the depth of the leather nor the length of the ram affects the total friction, since the effective portion of the cup is a curved surface where the contact takes place. With hydraulic machines in good order, the amount of friction may be taken to be 1 per cent. for rams of 4 inches diameter, and ½ per cent. for rams of 8 inches diameter, as will be seen by the table below.

From these experiments the following formula is deduced:—

$$F = \frac{P \times C}{D}$$

Where F = total friction of leather packing.
D = diameter of ram in inches.
P = pressure per square inch.
C = coefficient.

C = ·0471 with new, or badly lubricated, leathers.
C = ·0314 with leathers in good condition, and well lubricated.

The following Table of Mr Hick shows the frictional resistance in percentage of the total hydraulic pressure for rams from 2 inches up to 20 inches in diameter :—

D inches.	*F* per cent.	*D* inches.	*F* per cent.
2	2·00	12	0·33
3	1·33	13	0·30
4	1·00	14	0·28
5	0·80	15	0·26
6	0·66	16	0·25
7	0·57	17	0·23
8	0·50	18	0·22
9	0·44	19	0·21
10	0·40	20	0·20
11	0·38		

In this connection reference may be made to the arrangement for receiving the packing (described on p. 45) for the duplex cylinder forging press of Messrs Davy Brothers, where a groove is turned in the mouth of each cylinder to receive the packing leathers.

It is important, for the efficient working of hydraulic machinery, to have proper packing leathers. Much trouble and delay arises where this is not carefully attended to.

ANDERTON HYDRAULIC LIFT.

Mr Leader Williams adopted hydraulic power for lifting barges to connect the river Weaver with the Trent and Mersey Canal at Anderton. The difference of level being 50 feet, the process of locking had previously been tedious and expensive. The plan that was adopted consisted in constructing a wrought-iron aqueduct by which the canal was brought to a point where the barges could be best raised and lowered to and from the river. Mr Duer (who was resident engineer of this work) described it fully in a paper read before the Institution of Civil Engineers in 1876.

The wrought-iron aqueduct was 162 feet 6 inches long by 34 feet 4 inches wide, in three spans of 30 feet, 75 feet, and 57 feet 6 inches, and was divided into two channels by a central web, the depth of it and of the sides being 8 feet 6 inches. The water was 5 feet 3 inches deep, and with the aqueduct gave a total weight of 1050 tons. This weight was partly supported by columns which rested on cast-iron cylinders containing concrete, carried on masonry foundations built on piles. A water-tight connection was obtained by bolting the wrought-iron bottom-skin of the aqueduct upon a cast-iron bed-plate built into the masonry with a layer of red lead between. The outer edges were caulked with wooden wedges, and the sides run with Portland cement. Each end of the aqueduct was fitted with wrought-iron lifting gates, made water-tight by india-rubber strips fitted between them and the aqueduct. Each gate weighed 27 cwt., and was counterbalanced by weights. The lifting of a gate was effected in a minute and a half by a crab. The gate was raised 7 feet 6 inches clear of the water, which enabled the highest barge to pass under. The lift was double, so that by means of two troughs, with their floating barge load, the upper one, in descending, could be adjusted by the admission of water, so as to raise the lower one. These troughs were each 75 feet long by 15 feet 6 inches wide. The lighter barges held 30 tons, and the heavier 100 tons of goods. The troughs had lifting-gates at their ends like those on the aqueduct. One central vertical ram, 3 feet in diameter, supported each trough, whose weight (with the water and barge) was 240 tons, which is equivalent to a pressure of $4\frac{3}{4}$ cwt. per square inch of the ram. The rams were raised by presses controlled by an equilibrium valve for opening and closing communication between them. A 5-inch pipe connected these presses, and a 4-inch pipe conveyed the water from the accumulator to the presses. One man in a valve house at the top of the aqueduct worked the lift by means of shafting and gearing. When a trough descended into the pit, it was immersed fully 5 feet. The depth of water while the trough was being lifted, however, was not allowed to rise to

more than 4 feet 6 inches; the extra water was drawn off by syphons which dipped into the water while a trough was descending. The air within the syphon was driven out into the trough by its shorter leg, which nearly filled the trough with water. When it was again lifted, the syphon drew water (owing to the partial vacuum within it) out of the inside of the trough, and thus acted automatically. Each trough could, if necessary, be lifted separately by the engine and accumulator, but this occupied half an hour, whilst the double lift was made in from two to three minutes with a 10 h.-p. engine. A single lift could only take two barges up, or bring two down in eight minutes, with an engine of six times the power required for a double lift.

The abstraction of 15 tons of water from the canal (representing a layer of 6 inches over the bottom of the trough) provided the chief means required for raising a barge. The remainder of the power (about one-twelfth) was obtained from a small steam-engine and accumulator. The double-lift arrangement enabled expedition and economy to be secured, as each press alternately utilised the weight of the trough, which rested upon it, to raise the other trough from the low to the high level.

A saving of water also was effected as compared with locking, inasmuch as only 15 tons were used at each operation of raising a barge, whereas with a fall of 51 feet through a chain of six locks, a much larger quantity would have been wasted. Under the most unfavourable circumstances (for instance, when two similar barges have to pass each other through locks with this fall) the column of water taken from the upper level would have been equivalent to the area of one lock multiplied by the total fall. If, however, a series of barges had been arranged to follow each other in the same direction, less waste would have ensued. If six barges were to ascend with all the locks empty, the first would take five lockfuls, and the other five would take one lockful each from the upper level, making ten lockfuls for the ascending barges. A similar number of descending barges would take eleven lockfuls of water, making twenty-one

altogether, or 175 feet, whereas the lifts would have required six layers of water each 6 inches deep, or 3 feet, which was only 1·7 per cent. of that which would have been used for locking. This lift was capable of taking eight barges up and eight down in an hour. Assuming eight to have been laden with the average load of 25 tons each, the lift was thus able to transfer 12,000 tons per week, at a cost of 2·16 pence per ton. The parliamentary tolls were as follows:—Per ton for all goods, 1d.; for each laden barge, 1s.; for each empty barge, 2s. 6d.

The failure of one of the hydraulic presses at Anderton led to much investigation, as other similar lifts were being introduced at various places in France and Belgium, one being at La Louvière on the Canal du Centre near Mons. The observations that were made to determine the construction of the presses for the Louvière Canal lifts were interesting and important. It was originally intended that the press should be of cast iron, 6 feet 8 inches in internal diameter, with metal 4·72 inches thick. The pressure in the cylinder being 28 atmospheres (about 420 lbs. per square inch), the extreme tension would have been 1·65 tons per square inch. This was considered a safe load for the Belgian cast iron, which bears a tensile strain of 11·43 tons per square inch. The Terre Noire Steel Company of St Etienne, France, suggested a press of cast steel, constructed in the same manner as an ordinary cast-iron press, but of less metal. Some of these rings were cast and tested. One of them was kept under a pressure of 46 atmospheres for two hours, and proved perfectly water-tight. Trial bars cast at the same time broke at 31·16 tons per square inch, with an elongation of 8·6 per cent. Another ring, chosen haphazard, was tested. At 50 atmospheres an elongation of ·157 of an inch was measured. On removing the pressure, the press returned to its original dimensions. At 75 atmospheres the elongation was ·197 of an inch, and at 80 atmospheres the press suddenly failed. On examining the fracture a fault 5 inches long, and extending nearly through the whole thickness of the metal, was seen, due to a scale from the mould becoming detached, owing to the

high temperature of the casting. Judging from the trial bars, the press should have withstood 240 atmospheres. Owing to this failure it was determined to abandon this form of construction.

Messrs Cail of Paris next proposed a press of steel plates bent into a cylindrical form (like a boiler), with rivetted butt joints having internal and external cover-plates. A trial length was built up in rings 6 feet 3 inches high, with covering-rings at the joints. The steel plate was 1·02 inches thick, with a working tension of 7·17 tons per square inch. Although the rolled plate would stand 38 tons, the weakening due to rivetting reduced the margin of safety, and the joints could not be made water-tight. A trial length leaked badly under 30 atmospheres, and at 35 the pumps could not make up the leakage. Ultimately, the press cracked through the cover-plate and some of the rivets started, at a pressure which could not be definitely ascertained, but was between 48 and 70 atmospheres.

While these trials were going on, Messrs Clark & Standfield had been directing their attention to the placing of steel hoops round the cast-iron presses. The practical difficulty of getting the hoops over the flange of the press presented itself, and it was decided to make the hoops at the joints with flanges like the tire of a wheel. To prevent this flanged tire from being dragged off, a small projection was left on the body of the press, the heated tire was then passed over this, and, in cooling, it fitted tightly behind it. M. Kraft, chief engineer of the Société Cockerill, gave much consideration to the calculations for, and the method of constructing, these presses, and a trial segment was made by the Société Cockerill, as shown in fig. 29. This was tried under hydraulic pressure, the expansion being measured by a thin strip of metal put round the cast-iron cylinder, and another strip round one of the steel hoops. The two ends of each strip were connected by means of a spring adjusted by a screw, and were also joined to the short ends of an arrangement like proportional compasses, set to a ratio of 12 to 1. By this means any slight opening of the ends of the strips, caused by

the expansion of the cylinders, was shown twelve times its actual size on the long arms of the compasses. Owing to friction (which was, however, reduced to a minimum by lubrication) and other causes, the measurements were not absolutely correct, but the instrument was found to be very sensitive and constant. A satisfactory trial took place in the presence of the ministers, and many Belgian and French engineers interested in the undertaking.

In addition to this trial, M. Génard (on behalf of the Ponts et Chaussées) and Mr Lyonel Clark (on behalf of Messrs Clark & Standfield) carried out a series of exhaustive trials

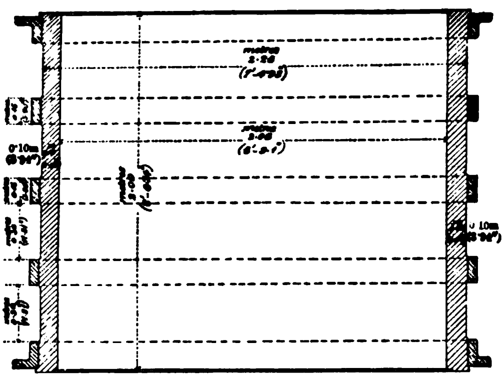


Fig. 29.

on the segment, for the purpose of finding out as nearly as possible the conditions of the several portions of this composite construction under various strains. It is evident that the cast-iron body is subject to a strain at the part covered by the steel coil entirely different from that to which it is subject elsewhere. Very many experiments were made, the pressure being increased gradually, and a measurement being taken at each increment of ten atmospheres. The mean of these, corrected for atmospheric temperature and other causes, was taken, and a normal curve plotted, which gave as the elongation on the cast iron between two coils, and elongations on one of the steel coils, the results shown by Table I.

TABLE I.

Actual Elongations of the Circumference.

	Pressure in Atmospheres.														
	10.	20.	30.	35.	40.	50.	60.	70.	80.	90.	100.	110.	120.	125.	
Elongation between coils,	208	·573	·960	1·05	1·361	1·805	2·235	2·662	3·07	3·447	3·717	3·966	4·254	4·604	Millimetres.
	·0082	·0226	·0378	·0413	·0535	·0714	·088	·1047	·1209	·1358	·1464	·1655	·1675	·1812	Inch.
Elongation on coils, . . .	·134	·349	·578	·666	·884	1·24	1·618	1·974	2·318	2·696	2·992	3·242	3·475	3·766	Millimetres.
	·0053	·0137	·0228	·0262	·0348	·0488	·0637	·0777	·0913	·1061	·1177	·1315	·1368	·1482	Inch.

Were the press a plain cylinder, it would be easy to deduce the tensions from these elongations, supposing the different coefficients of elasticity of the metal under the different tensions to be known; but in either case, before pressure was put on the press, the steel coil was already compressing the cast-iron body to some extent. The tensions had, therefore, to be deduced in two ways, by calculation and by graphic means. The sizes to which the coil was bored, and the press turned, were accurately known, and a pressure which would compress the cast iron and elongate the steel coil until they became of equal length was deduced. Although following different methods, both M. Génard and Mr Clark obtained nearly the same results. M. Génard found the pressure existing between the coil and the press to be 14 atmospheres, whilst Mr Clark found 13¾ atmospheres. When considering the measured elongations, the tension on the cast-iron body of the press is evidently relieved by this exterior pressure of 14 atmospheres, whereas the tension on the steel coil is increased to the same amount. They, therefore, found that the tensional strains were as shown in Table II. The strains at A are those on the cast-iron press directly under the steel coil, and those at B on the steel coil itself.

It will be noticed that, with the interior pressure of 10 atmospheres, the cast iron is still in compression, owing to the shrinking of the steel coils.

For that portion of the cast-iron part of the press which does not lie directly under the steel coils, it was more difficult to calculate the tensions, for it was nearly impossible to find out to what extent the shrinkage of the steel coil influenced this part. It evidently lay between the maximum (that is, assuming this part to be as much affected by the shrinkage of the coil as the part directly under a coil) and the minimum, assuming the coil to have no influence. Table III. shows the results.

The ordinary working pressure of these presses was 35 atmospheres (517 lbs. per square inch). In this condition, then, the strain on the cast iron under a coil was 1·35 kilogrammes

TABLE II.

	Pressure in Atmospheres.												
	10.	20.	30.	35.	40.	50.	60.	70.	80.	90.	100.	110.	
A, . . .	−·6	+·18	·95	1·35	1·72	2·5	3·275	3·95	4·7	5·4	6·05	6·7	Kilogrammes per square millimetre.
	−·381	·1143	·6032	·8572	1·092	1·587	2·076	2·508	2·984	3·429	3·841	4·25	Tons per square inch.
B, . . .	4·33	5·15	6·05	6·4	6·85	7·7	8·6	9·45	10·15	11·29	12·15	13·03	Kilogrammes per square millimetre.
	2·73	3·24	3·84	4·06	4·32	4·89	5·46	6·00	6·57	7·17	7·71	8·25	Tons per square inch.

TABLE III.

	Pressure in Atmospheres.												
	10.	20.	30.	35.	40.	50.	60.	70.	80.	90.	100.	110.	
Between	1·05	2·025	3·00	3·475	3·95	4·85	5·75	6·65	7·60	8·50	9·15	10·5	Kilogrammes per square millimetre.
	·667	1·28	1·905	2·2	2·51	3·08	3·65	4·22	4·83	5·397	5·94	6·67	Tons per square inch.
Coils	·57	1·7	2·7	3·175	3·65	4·55	5·43	6·33	7·23	8·1	9·0	9·9	Kilogrammes per square millimetre.
	·362	1·079	1·714	2·01	2·32	2·9	3·45	4·02	4·59	5·13	5·71	6·28	Tons per square inch.

per square millimetre (·857 ton per square inch), for the cast iron between two coils, 3·175 to 3·475 kilogrammes per square millimetre (2·01 to 2·2 tons per square inch), and for the steel coil itself, a tension of 6·4 kilogrammes per square millimetre (4·06 tons per square inch).

The limit of safety fixed by the Belgian Government for cast iron under tension was 2½ kilogrammes per square millimetre (1·59 tons per square inch), and for the steel 7 kilogrammes per square millimetre (4·76 tons per square inch). It is evident, however, that although that portion of the cast iron which falls under the coils, and also for some distance on each side of it, is working under safe conditions, there is a portion which exceeds these limits. It was, therefore, decided by the Government that whilst accepting this form of press, they considered it desirable that a greater number of coils should be shrunk on, and it was eventually decided to make these coils continuous from top to bottom.

In designing these lifts, the principle of the Anderton lift was followed, varied, however, in one important point. It has been stated, when describing the Anderton lift, that the upper trough with its barge is made heavier than the lower one, by the addition of a layer of 6 inches of water, which forces the lighter one up. When the heavier one, however, enters the water at the low level, the displacement of the water diminishes its weight, and requires the action of a differential accumulator to complete the work, by supplying the power necessary to overcome the difference of weight, and to force the rising trough to its proper height. In these lifts this accumulator, with the engines, boilers, pumps, and labour, are dispensed with, by arranging the works so that the descending trough is received in a dry basin from which the low level water is excluded by a gate similar to that applied at the high level. This alteration in the design enables the descending trough to complete the operation of raising the other trough through the full stroke of the ram. Fig. 30 gives a general view of the hydraulic canal lift at La Louvière.

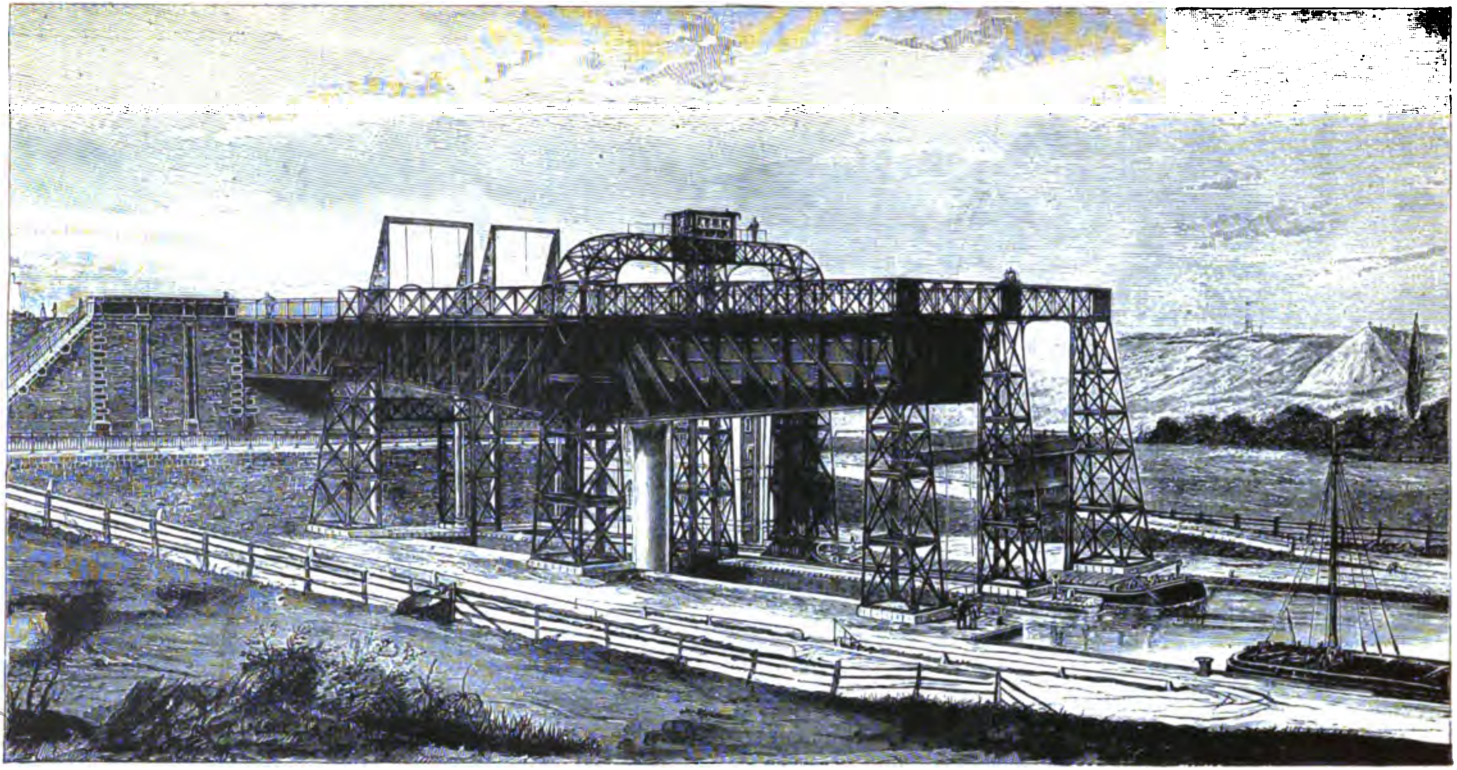
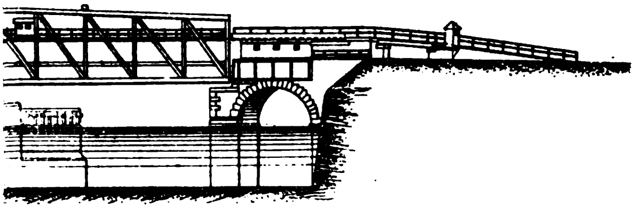


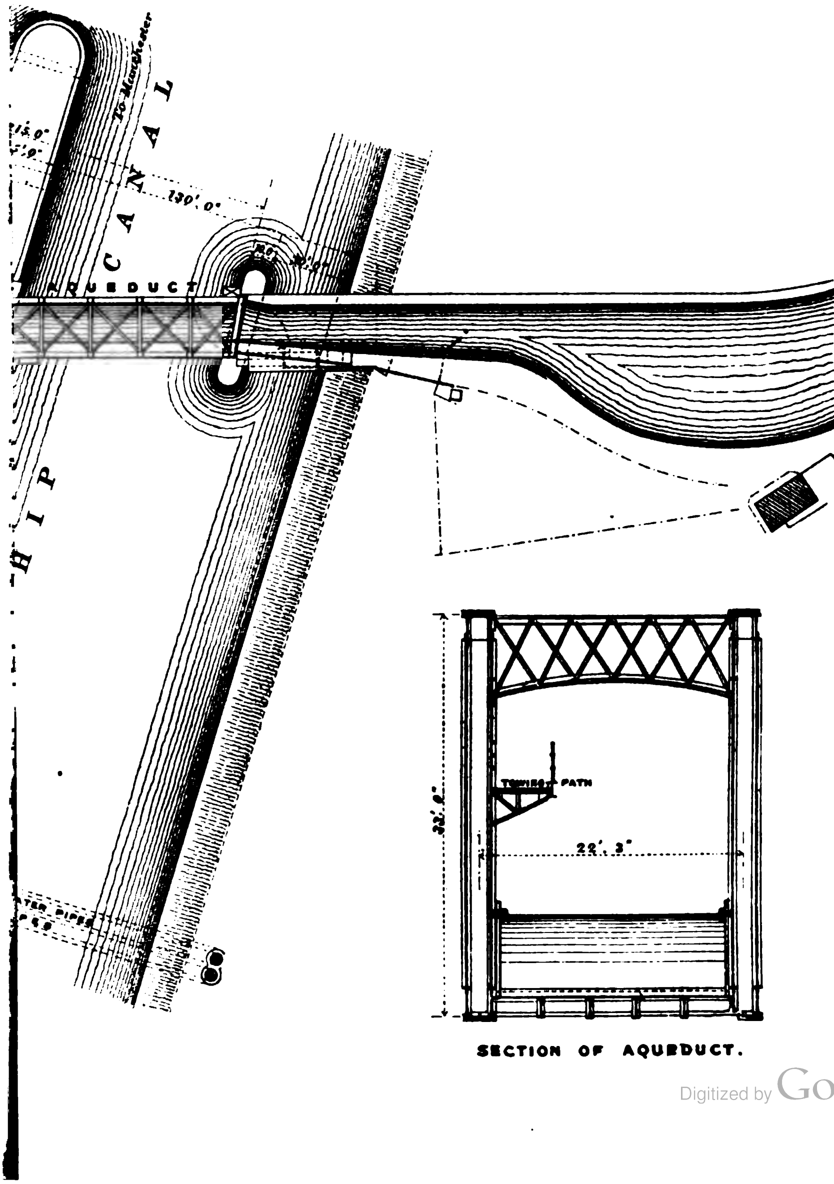
Fig. 30.

BARTON CANAL AQUEDUCT, MANCHESTER SHIP CANAL.

In the construction of the Manchester Ship Canal the then existing Bridgwater Canal had to be dealt with, as it crossed the Ship Canal. An interesting description of the work at this point was given by Sir Leader Williams at the Institution of Civil Engineers in 1897. He stated that the limited water supply of the old canal, the loss of water and time that would have occurred if two sets of locks had been constructed to enable barges to cross the Ship Canal on its level, as well as the inconvenience to vessels using the larger canal, made it advisable to adopt a movable aqueduct, which was an interesting way of dealing with the crossing of two canals, as a trough filled with water was swung like a swing bridge on a central pivot, leaving a passage on each side for vessels to pass along the canal, and at other times it was closed, enabling the Bridgwater Canal vessels to pass over (see Plate 7). The success of the lift at Anderton (referred to elsewhere) suggested that the same principle might be used for a swing aqueduct. The result is that the first canal aqueduct, constructed 136 years ago by Brindley, has been replaced by the first one made to open to allow vessels to pass through. The old aqueduct was constructed of stone and brick, with three arches, the canal waterway being 18 feet wide and 4 feet 6 inches deep. The new aqueduct has two movable spans of 90 feet each, with a waterway 19 feet wide and 6 feet in depth; it works on a central pier 400 feet long and 50 feet wide, which carries also the adjacent road bridge.

The pier is mainly built of cement concrete with brickwork and granite in the part that takes the weight of the aqueduct, 1400 tons, including the water which is always in the iron trough through which the barges pass. The sides of the trough are 1 foot above the water-level; it is carried by side girders 234 feet long, 22 feet 3 inches apart from the centres of the girders, which are 33 feet deep, tapering off to 28 feet 9 inches





SECTION OF AQUEDUCT.

at the ends, with a side tow-path carried on a gallery 9 feet above the water-level. Water-tight iron swing-gates are provided at each fixed shore-end and also at each end of the trough; when all four gates are open, barges pass along the canal as usual. If a ship is to pass through the aqueduct, all the gates are closed, the shore-gates keeping back the water in the canal, and the other gates confining the water in the trough when it is swung open for the passage of the ship. The gates are worked by hydraulic power, as is also the trough, which can be swung with barges in it, the gross weight to be moved remaining the same. At each end of the trough a water-tight joint is made by an iron wedge-piece of the shape of the cross section of the end of the trough, both ends and bottom being faced with india-rubber. The fixed and movable ends of the aqueduct are slightly tapered and about 1 foot apart. This vacancy is filled by the wedge-piece, which weighs about 12 tons, and is lifted by four hydraulic rams, sufficiently to allow the trough to be moved, the water between the gates being passed off into the Ship Canal. The junctions just described are not at right angles to the trough, but are slightly diagonal, so as to allow sufficient clearance for moving the trough. After it has been again closed, the wedge-piece is dropped on to its seating, being of the same taper as the ends of the trough and aqueduct.

The arrangements of the annular girder, rollers, etc., are the same as those for the heaviest swing-bridges, but half the weight of the movable portion of the aqueduct is taken by a central hydraulic press, 4 feet 9½ inches in diameter and 2 feet 3 inches deep, which acts as the pivot and is free to turn; a hydraulic buffer and locking bolts are also provided. The power is obtained from the adjacent hydraulic station, which is also used for the road swing-bridge; both are worked from a high brick tower on the central pier. The aqueduct has never given any trouble, working quickly and with smoothness—a result for which much credit is due to the constructors, Messrs Handyside & Co.

HYDRAULIC HOISTS—LIFTS.

A cage raised and lowered on the top of a ram (the cylinder being sunk in the ground) is the simplest form of hoist. Provision in this case has to be made for a varying weight due to the altered condition of the load. As the ram rises, the head and pressure diminish, whilst the weight of the ram increases, as it is less and less immersed in the water. A counterbalancing weight is, therefore, required to lower the cage when empty, and to adjust the varying weights of the chain as the cage rises and falls, and also to balance the weight of the ram. The counterweight is usually attached to the chains connected with the cage, and passing over fixed sheaves at the top of the lift-framing. The amount of weight to be provided must be sufficient to balance the cage and the whole weight of the ram when at the top of the stroke, *minus* the weight of the chain which then assists the counterweight. When the ram is at the bottom of the stroke, the counterweight must balance cage, ram, and chain, the weight of the ram being then less than when it was at the top of the stroke, owing to water surrounding it. It will be seen that where the weight of a direct-acting ram is counterbalanced, the ram is subjected to both tensible and compressive strains, according to whether the ram is being pulled by the counterweight or pushed by the water-pressure. If, on the other hand, the counterweights are omitted, the amount of water consumed to raise the load is greater in proportion to the useful work done.

Hydraulic power has a large field for useful employment in the direction of working lifts in offices, hotels, and private houses, where the height of the upper floors renders some mechanical appliance necessary.

THE OTIS ELEVATOR.

The low pressure of water companies' mains is capable of being utilised for lifts. A good form of low-pressure lift is that which is known as the "Otis Standard Hydraulic Elevator," manufactured by the American Elevator Company. The mechanical arrangements which are characteristic of this lift are shown in detail by Plate 8. The motor is a cast-iron vertical cylinder A connected by a tee C to a smaller cylinder B, the bottom of which rests in the water-chest D, connecting with the valve through the port E. The cylinder A is connected with the valve through the port F. The valve is a piston valve with a rack attached to the top of the piston, and is worked by the sheave T, attached to the pinion shaft, and controlled by a hand rope S passing through the car. In the cylinder A is a piston G connected by means of two piston rods, which pass through stuffing-boxes N to a crosshead K. This crosshead rests in a double strap I, which holds the travelling sheave H, connected with the car by means of four independent wire cables, one end of each being fastened to a hitching block by means of fork rods. The other ends, after passing under the travelling sheave H, and over the overhead sheave R, are led, two on either side, to the bottom of the car, where they are attached to the ends of the safety platform upon which the car rests.

The piston and the car thus travel in opposite directions; the former, with its attachments, balances a certain proportion of the dead weight of the car. The rest of the dead weight is counterbalanced by cast-iron blocks L placed in the strap I. Owing to the sheaves H and R the car has a travel of twice that of the piston G (the travel of which is never more than about 30 feet) so as to retain the solid column of water underneath it by atmospheric pressure, when it is at the top of the cylinder. The motive power is usually the hydrostatic pressure from the elevation of a cistern, so that the pressure rarely exceeds 40 lbs. per square inch. The speed is usually 300 to

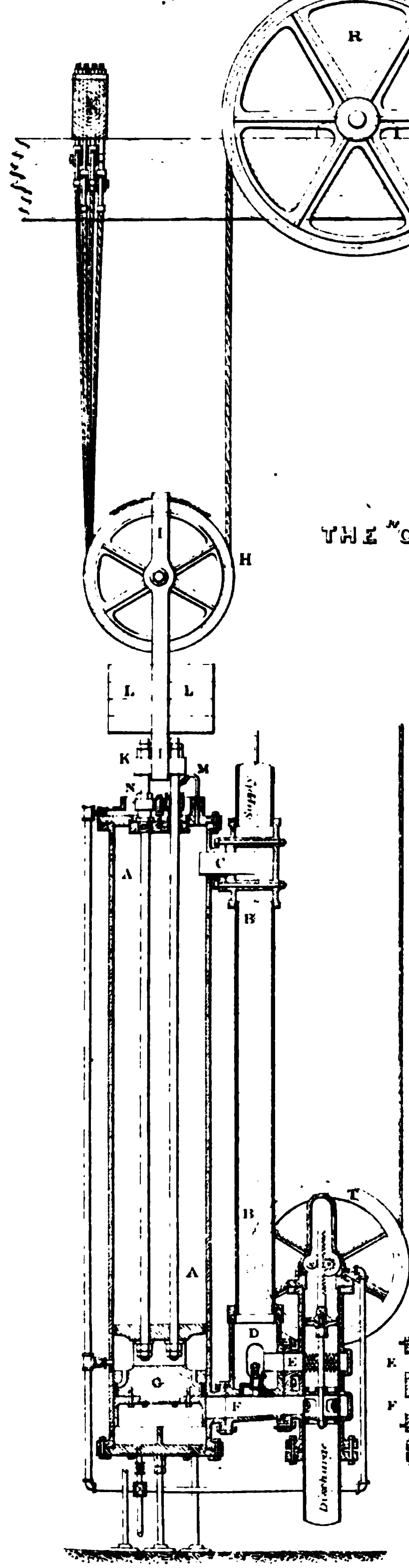
400 feet per minute. There are three pistons in the valve connected by a stem, the upper one being for the purpose of preventing the water from escaping through the valve cap at the top of the valve. The pressure on the bottom of this upper valve piston is equally on the top of the second piston, and enables the valve to be raised or lowered without effort.

The area of the cylinder A is made proportionate to the load to be lifted. The downward pressure is always constant on the piston G, but downward motion is impossible until the column of water which is underneath the piston G is allowed to move by the opening of the valve. The exhaustion of the column underneath the piston G is effected by raising the valve piston until it occupies the space between the ports E and F, as in fig. 2. This raising of the valve piston opens connection between the port F and the discharge pipe, enabling the column below the piston G to discharge, and the hydrostatic pressure on the top of the piston G to become effective in forcing the piston down to the bottom of the cylinder.

The column of water below the piston G will not fall away and discharge unless there is a pressure on the top of the piston, even if the piston G is at the top of the cylinder, as the column of water under the piston G is never more than 30 feet in height, and this column is sustained by atmospheric pressure. The available pressure is always the same throughout the entire stroke, for what is lost in head (when the piston G is near the top of the cylinder A) is balanced by the weight of the column which hangs to the bottom of the piston; and as the piston descends and the head increases, the weight of the column underneath the piston decreases.

For lowering the car, the valve piston is lowered below the port F into the discharge, and thus the pressure (which is also in the circulating pipe B) acts under the piston G as well as on the top of it. The pressure being thus neutralised, the car descends by gravity, raises the piston G, and displaces the column of water on the top of it. This water passes through the port C into the tee, and being prevented by the greater

Fig: 1.



THE "OTIS" ELEVATOR.

Fig: 2.

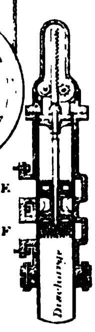
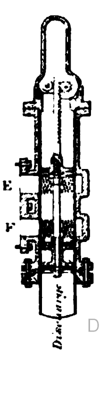


Fig: 3.



pressure from going up the supply pipe, it passes through the circulating pipe B into the valve, back through the port F under the piston G, filling the cylinder A under the piston, as the piston ascends. The discharge of this water is prevented by the position of the valve piston, as shown in fig. 3, and thus the water which was on the top of the piston G is led below it, ready to be discharged the next time the car is raised. The solid column of water thus acts on both sides of the piston, so that no action of the piston can take place without a displacement of water, which can only be produced by a change of the position of the valve. All motion is stopped when the valve piston covers the port F (as in fig. 1) without regard to the position of the piston G, for the column below the piston G cannot be discharged while the valve piston is covering the port F. Nor can circulation take place, because that same position of the valve piston prevents the flow of the water from the circulating pipe B under the piston G, the head in the supply preventing the water above the piston G from being forced up the supply pipe.

Attached to the piston G is a cast-iron apron, or follower, which automatically cuts off the discharge at port F, in the downward stroke of the piston. The discharge is cut off before all the water is exhausted from the bottom of the cylinder A, and, therefore, this water forms a cushion on which the piston seats itself gradually. To prevent the accumulation of air underneath the piston G, an air valve is attached to the piston by which the air passes through the piston to the top of the cylinder A, and then either passes out through the supply pipe or is exhausted by means of a jet cock M. When the travel of the piston G is suddenly arrested, the shock is overcome by means of a relief valve, connecting the water-chest D with the port F, enabling the water under the cylinder to communicate the shock through this valve to the column in the water-chest D and circulating pipe B, on into the supply pipe. In case of a sudden stoppage of the piston G in an upward stroke, the shock finds

vent through the port C up into the supply pipe, and is also overcome.

There are never less than four cables used, and the smallest size is half an inch diameter. The diameter decided upon in each case is such that any one cable shall have many times the necessary strength to do all the work. These cables are so attached that they receive an equal strain, and in case of the breaking of one, there is nothing to occasion the breaking of any of the others. The four cables are attached to the safety platform underneath the car, and are so arranged that the car will not work unless the strain on each cable is equal. By this means the mere stretching of one cable makes it impossible to run the car until the stretch shall have been adjusted by means of the fork rod, by which it is attached to the hitching-block.

Under the car is a safety platform, consisting of hard wood faced with iron plates. At each corner is an iron shackle rod, to each of which a cable is attached. These shackle rods are fastened to an equalising bar underneath the platform, which is held by a pivot in the centre, and so long as the strain upon the two cables is equal, the bar will retain a horizontal position, but the stretching of a cable will allow the bar to leave its horizontal position, in either one direction or another, according to which end receives the greater strain. The shape of this equalising bar is such that, when it leaves the horizontal position, the forged projections of the bar come in contact with other forgings, which are a part of the wrought-iron rod that is extended from end to end of the safety platform on its underside. One of the forgings of this rod is a finger with toothed end. The normal position of this finger is just below a brass wedge which travels with the safety platform, and is held in place by means of a shoulder both on the top and side, and is thus prevented from falling out. The platform is grooved at either end to receive the hard wood slide on which the car travels. The jaws and ends of the safety platform are faced with heavy iron plates. The position of the wedge is between the guide and one of these jaws, and, from its shape, a pressing

in of the wedge creates so great an amount of friction that the car cannot travel. The wedge is pressed into its place by the finger before alluded to, and that finger is in turn worked by the mere stretching of a cable. Each end of the safety platform is equipped alike, and the rod which passes underneath the platform connects the two ends, so that action at either end necessitates the pushing in of the wedges at both ends. These wedges cannot slip out of position, nor can the slides warp out of place, or fail to be wedged. An adjustment and equalising of the tension of the cables which may have stretched, will at once remove the fingers which press in the wedges, and an upward motion of the car itself would at once release the wedges, owing to their shape. Downward motion is then possible, but it is impossible until the tension of the cables is equalised. It follows, then, that the heavier the weight in the car, the greater the power there is pressing in these wedges and the teeth of the end of the finger, which comes directly in contact with each wedge.

There is also a safety governor which has a separate attachment to the car by means of an independent wire cable. This passes through the governor, under a sheave at the bottom of the well in which the car runs, and back again to the side of the car, where both ends are attached. The governor is made for whatever speed may be desired, and any speed in excess of that would cause it to act.

Messrs Tommasi and Heurtvisé have devised a plan to balance the dead weights by means of a second hydraulic cylinder placed closed to the lifting cylinder, and connected with it. The ram in this second cylinder is loaded so as to balance the lifting ram and cage when at the bottom. It has a larger area but shorter stroke than the lift-ram, and is continued of the same diameter, through a stuffing-box, to another cylinder above it. The pressure in this latter cylinder, acting on the ram, balances the lifting ram in the lifting cylinder with its cage when at the bottom. Counter-weights serve to further balance the lifting ram as it rises, so that the pressure required

to be applied to the lifting ram is only that which is necessary to raise the people in the cage, and the lifting ram is (as it should be) always in compression.

GLASGOW HARBOUR ELEVATORS.

The elevators at the Glasgow Harbour Tunnel (of which Messrs Simpson & Wilson were the engineers) are worked by hydraulic power, and a description of them was given in *Engineering* in 1895 (when the tunnel was opened for traffic). They were constructed by the Otis Elevator Company, and deserve special mention, as they were more powerful than any that had been then made, the load being 12,000 lbs. and the maximum lift 72 feet. They work in the shafts on the north and south sides of the harbour, there being six in each shaft—three for lifting and three for lowering vehicles, for which they are intended, as the passenger traffic is served by inclined approaches to the tunnel and stairs.

The guides for the cars consist of posts of box section 10 inches by 12 inches, with cross struts at three intermediate points. Bolted to the guides are three thicknesses of pitch pine spiked together.

The elevating or lowering car has an automatic balanced lever arrangement to stop it on reaching the end of its journey.

The main elevating and lowering valves are identical, except that one of the bottom cups of the lowering valve is reversed for lowering. The fact that three elevators are used for lowering, and three for raising, involved some interesting features. The elevating machines have cylinders 13 inches in diameter, with a ram 10 inches in diameter, and the lowering machines a cylinder of 11½ inches in diameter, and a ram 10 inches in diameter. The lifting machine, in contradistinction to the lowering machine, has a preponderance of weight on the car side, so that it will just descend at a given speed by

gravity, the main valve being so connected that pressure is admitted above the piston to lift the load, or communication is established from above the piston to the discharge tank, the car descending. The machine, however, uses water pressure in proportion to the load lifted, there being two powers. For loads of 6000 lbs. or less, the motor uses 37·8 gallons in lifting the load 74 feet, and above 6000 lbs. load the consumption of water is 70·7 gallons for the same travel. This change of power is entirely automatic in action, and is brought about by the use of a valve designed by Mr Thorpe.

A small pressure pipe from the hydraulic-pressure mains communicates with the cylinder above the piston of the Thorpe valve, while below the piston is a pipe communicating with the main cylinder head. The pressure in the latter pipe is proportional to the load upon the elevating car. The areas above and below the piston of the valve are so proportioned that, at the desired changing point, viz., 6000 lbs., the effort beneath the piston exceeds the effort above, and the valve rises. In other words, it may be described as follows: In raising a car with a load of less than 6000 lbs. as above, the Thorpe valve remains closed, so that the water beneath the main piston lifts the balance check valve, and is forced into a pipe connected to the main cylinder head. When lowering the car, however, the balance check valve closes, and the unbalanced check valve lifts, thus opening communication from below the piston to the discharge tank. An amount of water equal in volume to the space beneath the piston is drawn in below the piston, and on the reverse stroke, or when lifting, this water is introduced above the piston. Thus the actual amount of water used is equal to the displacement of the plunger only. When lifting loads exceeding 6000 lbs., the preponderance of effort is below the piston of the Thorpe valve, causing it to rise and open communication directly between the valve and the discharge tank.

The lowering cylinder is 11½ inches in diameter, and the ram 10 inches in diameter. The weight of the car is overbalanced, so that the tendency of the unloaded car would be to rise, but when

loaded, to descend, thus using no water, the water in this case serving only as a brake. The main valve, therefore, has no direct communication with the accumulator pressure (which is 750 lbs. per square inch), but simply controls the egress of water below or above the piston for the ascending empty car or descending loaded car. In cases, however, of a vehicle being too light to overcome the overbalance and friction of the machine, there is a pressure valve worked by a lever alongside of the main lever on the operating gallery. By means of this valve the accumulator pressure is introduced below the main piston, and by placing this valve in the opposite position, pressure is obtained above the piston, in which way the machine may be used for lifting purposes. Attached to the lowering machine is a speed governor or controller, so that with the main valve fully open for the down motion there is practically no variation of speed, with just sufficient load to make the car descend, or with the car loaded to double its capacity.

At the head of each lowering cylinder is a safety valve, so that pressure above a certain point cannot be reached. There is also a similar check or relief valve, so that should the pressure be admitted from the auxiliary valve to the top of the main cylinder and the main valve be closed, a pressure above that in the mains could not be produced below the main piston. This check valve opens against and directly into the pressure mains. In the same manner, were the car ascending empty, *i.e.* by gravity, using no water, and the main valve suddenly closed, this relief would open, preventing the slackening of ropes, and gradually absorbing the inertia of the machine.

MERSEY RAILWAY LIFTS.

The railway under the river Mersey (which was constructed by the late Sir James Brunlees and Sir Douglas Fox, and was opened by the then Prince of Wales in January 1886) has at each extremity hydraulic lifts for conveying passengers and

their luggage from the deep underground stations at James Street and Hamilton Street to the daylight stations on the street level above. Particulars of these lifts were given in a paper read at the Institution of Civil Engineers by the late Mr Rich (of the firm of Easton & Anderson, their constructors). Plate 9 shows the arrangement. The lifts at the James Street station have a stroke of 76·6 feet, and at the Hamilton Street station 87·7 feet. At each station there are three lifts independent of one another, each being capable of raising one hundred passengers at a time. The maximum load due to passengers is taken at 15,000 lbs. The lifts are direct-acting, with rams of hollow steel 18 inches in diameter, with balance chains and counterweights. The ascending cage is 19 feet 6 inches long by 16 feet 6 inches wide and 8 feet 10 inches high. They are worked by low pressure water derived from a tank, aided by water pumped by steam-power direct into the lift supply-pipe. The water is discharged by the descending cages into an underground tank, from which it is pumped back to the high level tank.

The several lifts are contained in rectangular vertical shafts, 21 feet long and 19 feet wide, partly excavated out of the solid red sandstone, and partly in walls of brickwork. In the centre of each lift space a boring has been carried vertically beneath the floor to a depth of 75 feet to receive the lift cylinders, which are of cast iron, 21 inches internal diameter and 1½ inches thick, bolted together in 12-feet lengths. The rams are 18 inches outside diameter and ½ inch thick, constructed of mild steel tubes in lengths of 11 feet 6 inches, and connected together by internal screwed ferrules, 6 inches long and 15¾ inches internal diameter. The cage is guided and kept in position by four cast-iron guide brackets (of a V-shape) 16 inches long. From the side girders two chain pulleys, 4 feet 8 inches in diameter, are suspended. Between each pair of them is a counterweight weighing 7620 lbs., capable of being increased by smaller weights of 90 lbs. each to balance the lift. A large self-acting flap-valve admits

water automatically to the lift cylinder from the exhaust, if the starting valve is closed too suddenly during the ascent of the lift. The stroke of the hand-rope, from full pressure to full exhaust, is 9 feet, which enables the starting and stopping to be effected quietly. Three 7-inch mains descend to each lift from the bottom of the supply tank, with the necessary valves to control the service. The speed is about 2 feet per second, and the average journey is accomplished in from thirty to forty seconds. The three lifts at each station are capable of working simultaneously, raising three hundred passengers in about a minute. The total cost of the six lifts with all machinery was about £20,000.

CITY AND SOUTH LONDON RAILWAY LIFTS.

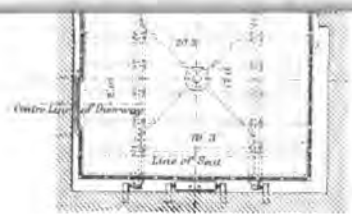
These were described by the late Mr Greathead in a paper read at the Institution of Civil Engineers in November 1895.

It was decided to adopt suspended lifts in preference to direct-acting lifts, as being lighter and, for large lifts, more rapid, and, owing to the absence of deep wells, as having every part open to inspection and accessible at all times. It may be interesting to note that this application of the suspended form is a return by Messrs Sir W. G. Armstrong, Mitchell & Co., to the original lifts of Lord Armstrong, introduced nearly fifty years ago and described in the *Proceedings of the Institution*, vol. ix. p. 376. Suspended lifts would not in all cases be the best form, direct-acting lifts having preponderating advantages in many cases.

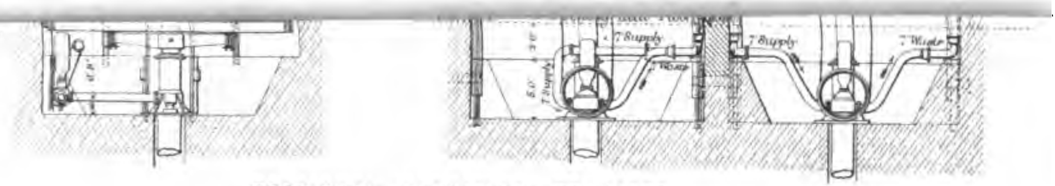
There are two lifts in the 25-foot shaft at each station, of depths varying between 43 feet at Stockwell and 67 feet at King William Street. The cages are approximately semicircular in plan, and each accommodates between fifty and sixty passengers, who enter and leave at either end. The lifts are worked quite independently of one another. The whole of the lifts are worked by pumping engines placed in the engine-room

MERSEY RAILWAY HAMILTON STREET STATION.

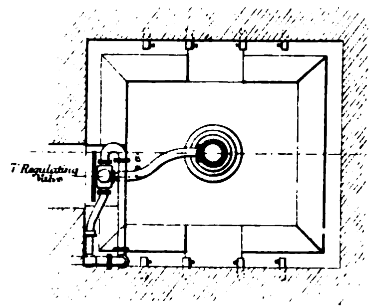
ARRANGEMENT OF PASSENGER LIFTS AT BIRKENHEAD.



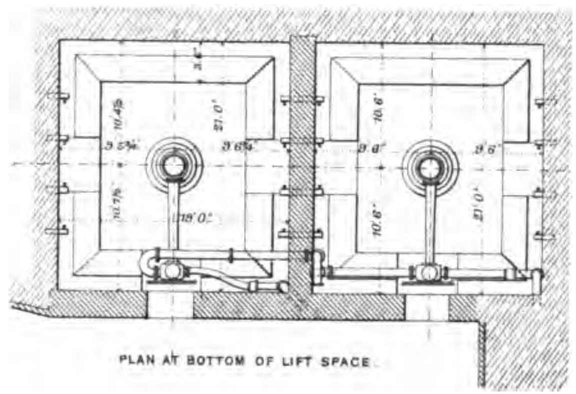
SECTIONAL PLAN OF CAGE.



SECTIONAL ELEVATION OF LIFTS.



PLAN AT BOTTOM OF LIFT SPACE.



PLAN AT BOTTOM OF LIFT SPACE.

Thos Kell & Son, Lith

at Stockwell, where the pressure in the main is about 1200 lbs. per square inch. The pressure and return-water pipes are carried upon brackets placed in the tunnels. In addition to the main accumulator at Stockwell, another is placed in the stair-shaft at the "Elephant and Castle" station for the purpose of equalising the pressure.

LIFTS FOR SUBWAYS.

Hydraulic power has another new field for utilisation in the direction of working lifts for subway traffic, both vehicular and passenger. In many cases where the construction of a bridge to convey traffic over a river is objectionable, a subterranean communication has been difficult to make, owing to the approaches to the subway being impracticable. Mr Greathead

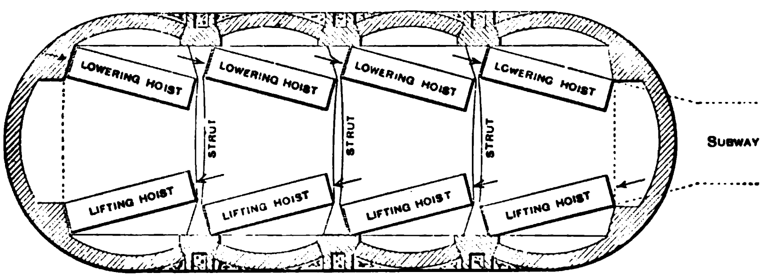


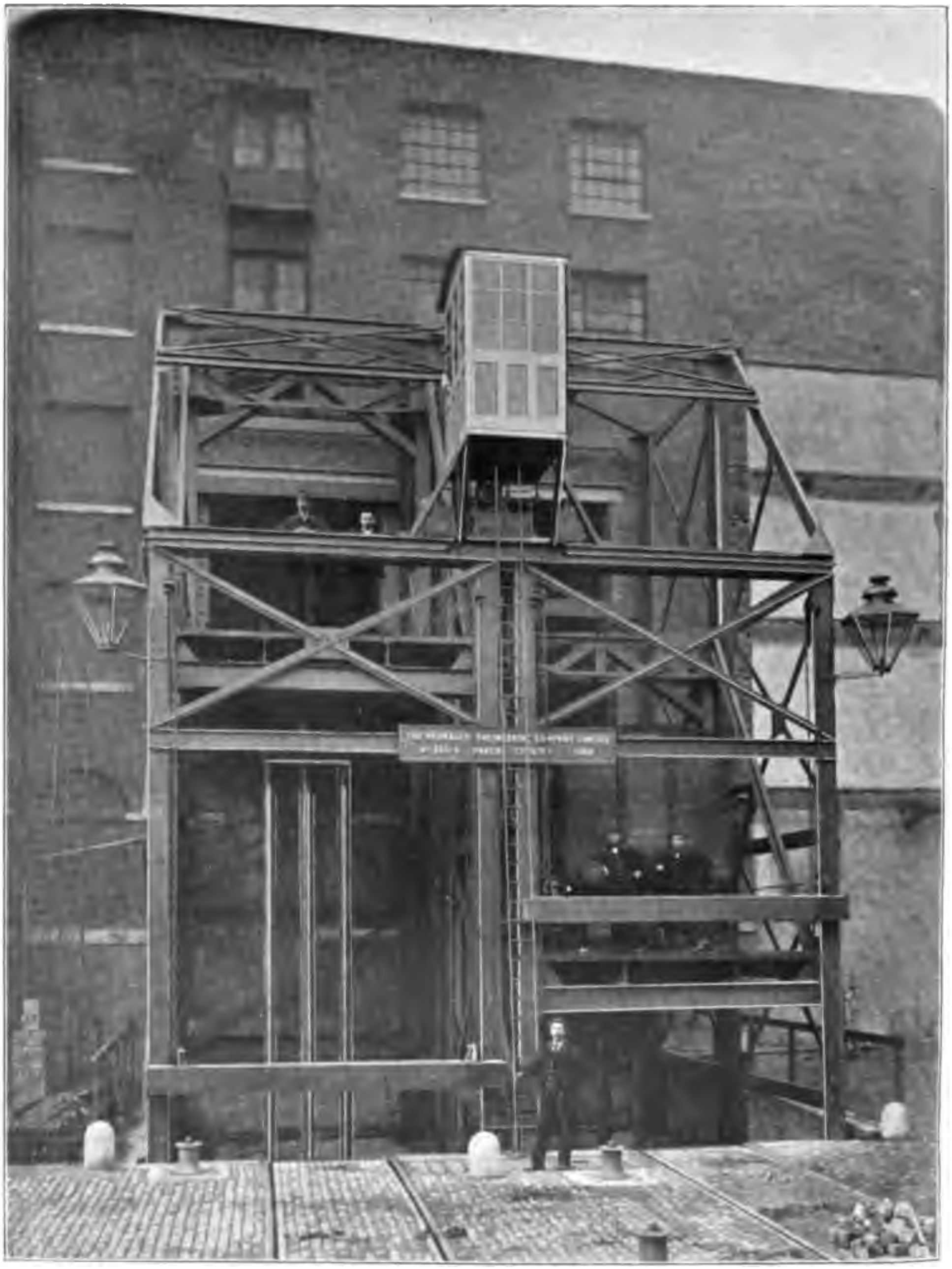
Fig. 31.

and Sir William Armstrong, Mitchell & Co., have given much attention to the question of providing hydraulic lifts which would enable the long and expensive approaches to a subway to be dispensed with, and which would at the same time meet uninterruptedly the demands of a large vehicular traffic.

An example of this is shown by fig. 31, which represents the arrangement of hydraulic lifts which it was proposed to be placed on Tower Hill and on the Surrey side for giving access to and from a subway under the Thames where the Tower Bridge has been since constructed. Two series of cages or compart-

ments (which were to be well lighted) were arranged to admit of free ingress and egress for the traffic going in both directions. One series was for lowering the traffic going southwards through the subway, and the other was for raising the traffic coming northwards from the subway. Each of the compartments was of such a size as to take either the largest vehicle and four horses, or a tramway car and horses, or two smaller vehicles and their horses. The working of the lift is as follows:—A vehicle arriving would pass into, say, the first of these large compartments, and be lowered immediately to the roadway below. The vehicle following would pass into the next compartment and be lowered. By the time the last of the series of lifts or compartments had gone down, the first would be back again at the surface for a repetition of the operation. The traffic would thus pass down continuously on that side, whilst a similar series of lifts at the other end would in a similar way take it up. The cost of the whole communication, including subway, shafts, lifts, subway for foot passengers, etc., in complete working order, was estimated to be £280,000, while a similar communication with inclined approaches would cost probably three times as much, and would involve the demolition of buildings and the displacement of population.

A subway can thus be approached at whatever depth it might be below the surface, and without the difficulty attending approaches with steep gradients, provided the number of lifts be proportioned to the traffic. The advantages of such a system of lifts are apparent. The continuity of traffic is not interrupted as in the case of a ferry or an opening bridge. No inclines have to be surmounted. Owing to the distribution of the traffic through a series of cages, the working expenses of lifts are in proportion to the traffic, whereas when large platforms are used, as hitherto, capable of taking a considerable volume of traffic, the working expenses are frequently out of proportion to the traffic, because at slack times the large platform is set in motion for one small vehicle. There is a great saving in first cost of communication compared



G. & N.-W. Railway Direct-acting Wagon Lift.

with the cost of a subway having inclined approaches, or with a subway having a large platform. By the multiple-lift system struts can be put between the deep walls of the shafts (as shown in fig. 31), which would be impossible if the single-lift system were employed. An arrangement of lifts like these effects a great saving of time to vehicles passing from bank to bank of the river. For instance, the lifts in the case shown by fig. 31 would take half a minute to go down and the same to go up, and assuming a vehicle to travel at three miles an hour through the subway, it would only take five minutes from bank to bank.

The cheaper means of making communications under rivers which this system of lifts affords, appears to open out a very important extension of the application of lifts. In some cases any additional communication has of necessity to be cheaply effected. The amount, or nature, of the traffic in many cases is such as to require that only a small outlay is incurred to make the work remunerative.

WAGON LIFTS.

Plate 10 shows two direct-acting wagon lifts which have been recently erected by the Hydraulic Engineering Company for the London and North-Western Railway, at their Goods Depôt at Haydon Square. Each lift is capable of raising and lowering loads of 20 tons through a height of about 21 feet, at a speed of about 100 feet per minute, with a working pressure of 600 lbs. per square inch. The rams are arranged to return water to the accumulator when lowering.

The lifting rams are three in number, the two outer ones being 7¼ inches diameter, and the centre ram 8½ inches diameter, working in separate cylinders, side by side, under the centre of the platform.

The rams are so proportioned that the centre one will raise the empty platform, the two outer ones will raise an empty wagon

in addition, and the three rams together will raise full wagons. In lowering with empty wagons of a maximum weight of about 4½ tons each, the centre ram returns its water to the accumulator. When lowering loaded wagons of a gross load of not less than about 15 tons the two outer rams return their water to the accumulator. All three cylinders are exhausted to lower the empty platform.

When not taking pressure water, the lifting cylinders are filled from a return tank.

NEW HYDRAULIC LIFTS OF THE EIFFEL TOWER.

An interesting description is given in *Le Génie Civil*, 1900, of new hydraulic lifts which were put in the Eiffel Tower in view of the Exhibition of 1900.

These were fixed in the eastern and western pillars of the Tower, and each is arranged to carry 8000 passengers in ten hours to the second stage, a height of 374 feet. The general conditions to be fulfilled were to raise 100 passengers (nearly 7 tons), the cars weighing over 9 tons, at a maximum speed of 8 feet per second, absorbing approximately 420 h.-p. By an arrangement of high and low-pressure accumulators (the latter being charged by the down journey of the cars) the mean horse-power required to be maintained by the pumps is reduced to about 70 h.-p. Three accumulators were used, two high-pressure, working at 770 lbs. per square inch, and one low-pressure, working at 256 lbs. per square inch, the pumps having to overcome the difference in pressure between the two systems. The cars were raised by steel wire ropes attached to rams of which the plungers were 15½ inches diameter and had a stroke of 55 feet, eight turns of cable being used. Each lift consists of a tier of three cars, the upper cars taking fifty passengers each, the lower one being arranged as a platform for the driver. Owing to the curved form of the pillars of the Tower the angle of the cars changes considerably during the ascent; the passenger

cars are therefore hinged on the carriage to which they are attached, and coupled together by a connecting rod which controls their movement, being coupled to a worm wheel fixed in the driver's car. The worm which drives this wheel receives its motion from a ratchet toothed rail, which is also used for the safety gear. This gear is so arranged as to automatically come into action whenever the speed exceeds 12 feet per second. Additional hydraulic brakes are also provided for use in case of necessity. The movement of the cars is controlled by a flexible steel cable which is attached to two partially balanced valves in the base of the Tower, one of which, for the up journey, admits high-pressure water from the accumulators to the ram; the other, for the down journey, regulates the exhaust from the rams to the low-pressure accumulator.

GRAIN ELEVATORS.

Mr W. H. Lindley, the Engineer to the Magistracy of Frankfort-on-Main, erected grain elevators in the new harbour at Frankfort, of which Plates 11 and 12 show the general arrangement, the object being to raise grain from ships and barges alongside the quay by a telescopic tube containing within it a series of buckets working vertically, and lifting the grain from the hold and delivering it to the surfaces of endless bands, which convey it to the various floors of the granaries for storage.

In order to raise the grain from the barges, a stationary elevator was fixed on to a swinging arm, at a distance of 7½ metres from its axis, as shown by Plate 11. The weight of the elevator and of the swinging arm A was partly counterbalanced by a number of weights. When the swinging arm was in a horizontal position the whole of the counterbalance weights were in action, and when the swinging arm was raised further up, the weights gradually came out of action. The counterbalance weights were connected to the elevator by means of two wire cables B B, and

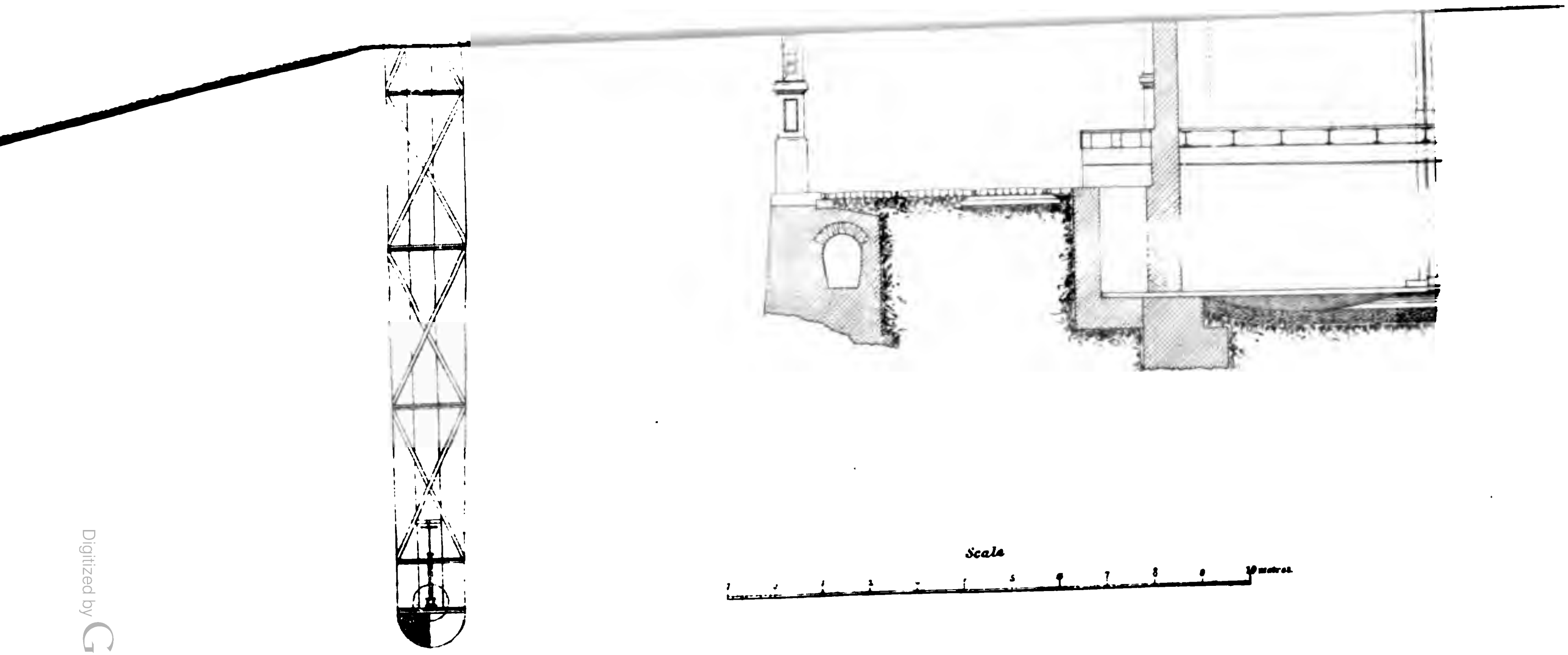
in such a way that the depression of the swinging arm takes place owing to the weight of the unbalanced part of the elevator, and it was raised by means of the wire ropes C C running over the winding drums of the windlass D. An improvement was introduced by substituting for the counterbalance weights hydraulic arrangements.

The grain lifted from the barges was taken from the top of the elevator by means of an india-rubber band, and was conveyed either to automatic scales, or to the transporting belts, for distribution and storage in the granaries, provision being made for dealing with 36 metric tons per hour, or 6 sacks per minute, each of 100 kilos. or 220 lbs.

In order to supplement the stationary grain elevator at the granary, a portable grain elevator was erected as shown by Plate 12. This elevator had a radius of 5 metres, and transported the grain from the barges to the two automatic scales A A and to the arrangements for filling and removing the sacks at B. This, as well as the stationary elevator, were capable of dealing with 36 metric tons of grain per hour, or 360 sacks each of 100 kilos. or 220 lbs. The portable elevator moved along the edge of the quay on rails of the ordinary gauge. The rotating part of this elevator was carried on rollers running on a race C C supported by the upper frame of the travelling truck, and while the elevator was at work it was supported on jacks D resting on the edge of the quay wall. The elevator could be altered to suit the varying water levels by means of a telescopic arrangement E, and the range of adjustment of the inner telescope tubes, as well as of the buckets, was 7 metres. The edge of these tubes was lowest when their highest position was ½ metre above the rail level, as shown.

The adjustment of the telescopic tube could be varied either when the elevator was at work or when it was at rest, and the weight of the telescope tube and buckets was balanced by counterweights F F at the back of the elevator. G G was the main driving belt. H was the windlass for lifting the telescope and the bucket belts. I was the band for transporting the grain.

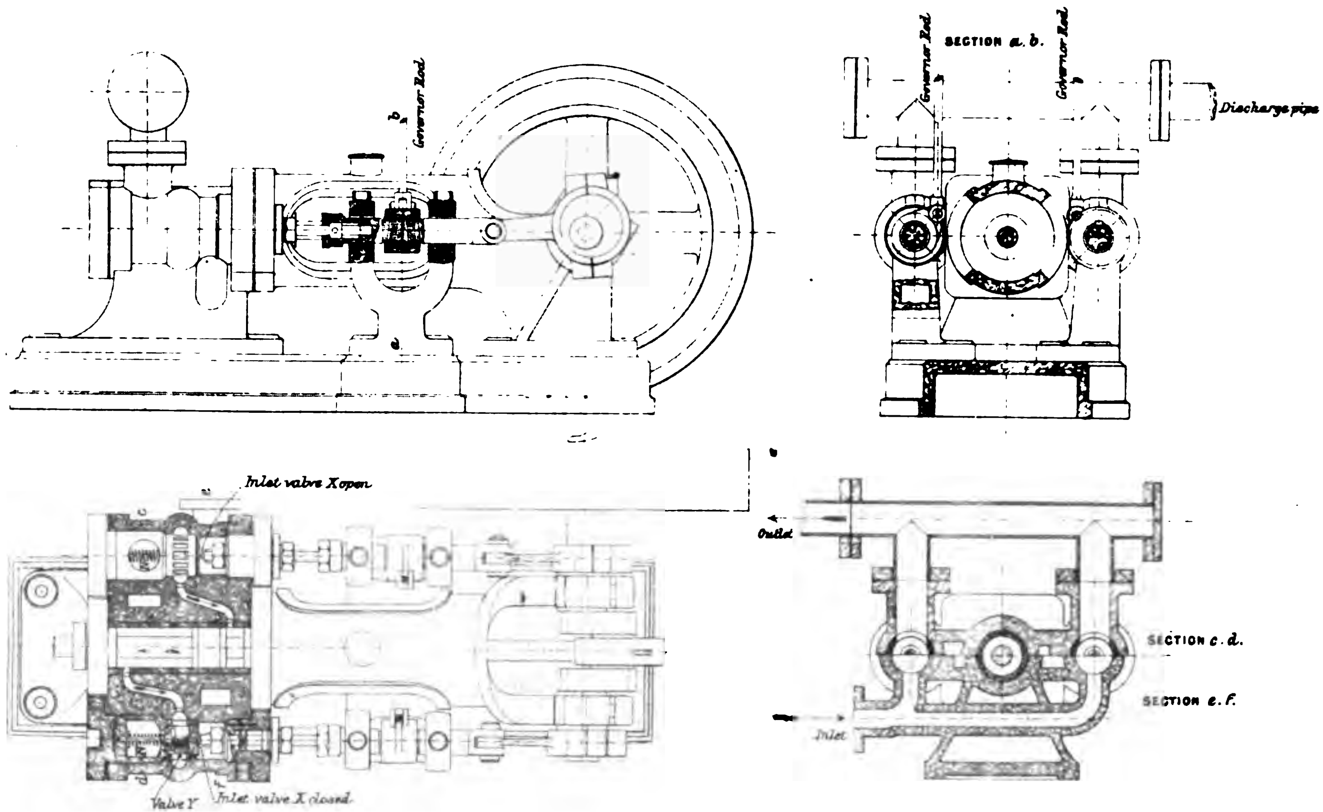
GRAIN ELEVATORS, FRANKFORT.



West, Newman Pho...

West, Newman Photo

HYDRAULIC ENGINE FOR MOVEABLE ELEVATOR, FRANKFORT.



West, Newman Photo

Grain Conveyancing Machine, Throwing-off Apparatus.

after it had been raised by the elevator to the weighing machine. J was the high-pressure water main, and K the exhaust.

The elevator was raised or lowered by means of a hydraulic engine, and could be placed at any desired part of the quay, and supplied with water at a pressure of 55 atmospheres from hydraulic mains, which were laid throughout the harbour for this and other purposes (Plate 13).

The Elswick Company have arranged grain-conveying machinery in which the grain is loaded on to an endless band by which it is carried to any desired part of the building, and often for very considerable distances. Plate 14 shows more particularly a movable throwing-off apparatus by means of which the load can be taken off the band at any desired position. The band after going over the top roller is suddenly bent downwards beneath the lower roller, but the grain is carried forward by its momentum, leaving the band at the roller and being received into a hopper or shoot a little way in advance. This class of machinery was originally introduced into this country at Birkenhead and Liverpool some forty years ago by Mr Percy Westmacott, and its use has since extended very much indeed.

WAYGOOD'S LIFT AND HOIST.

A form of hydraulic lift made by Messrs Waygood & Co., London, deserves mention, as automatic water-saving arrangements are applied to it whereby the water used is always proportional to the load raised. This is effected by admitting water to one or more rams through valves which are controlled by a governor driven by the moving lift at a speed varying with the load. With a light load the governor is driven quickly and actuates a weighted catch lever which limits the admission of water to one. If the load is heavy the slow movement of the governor enables water to pass two or more rams.

STAGE MACHINERY.

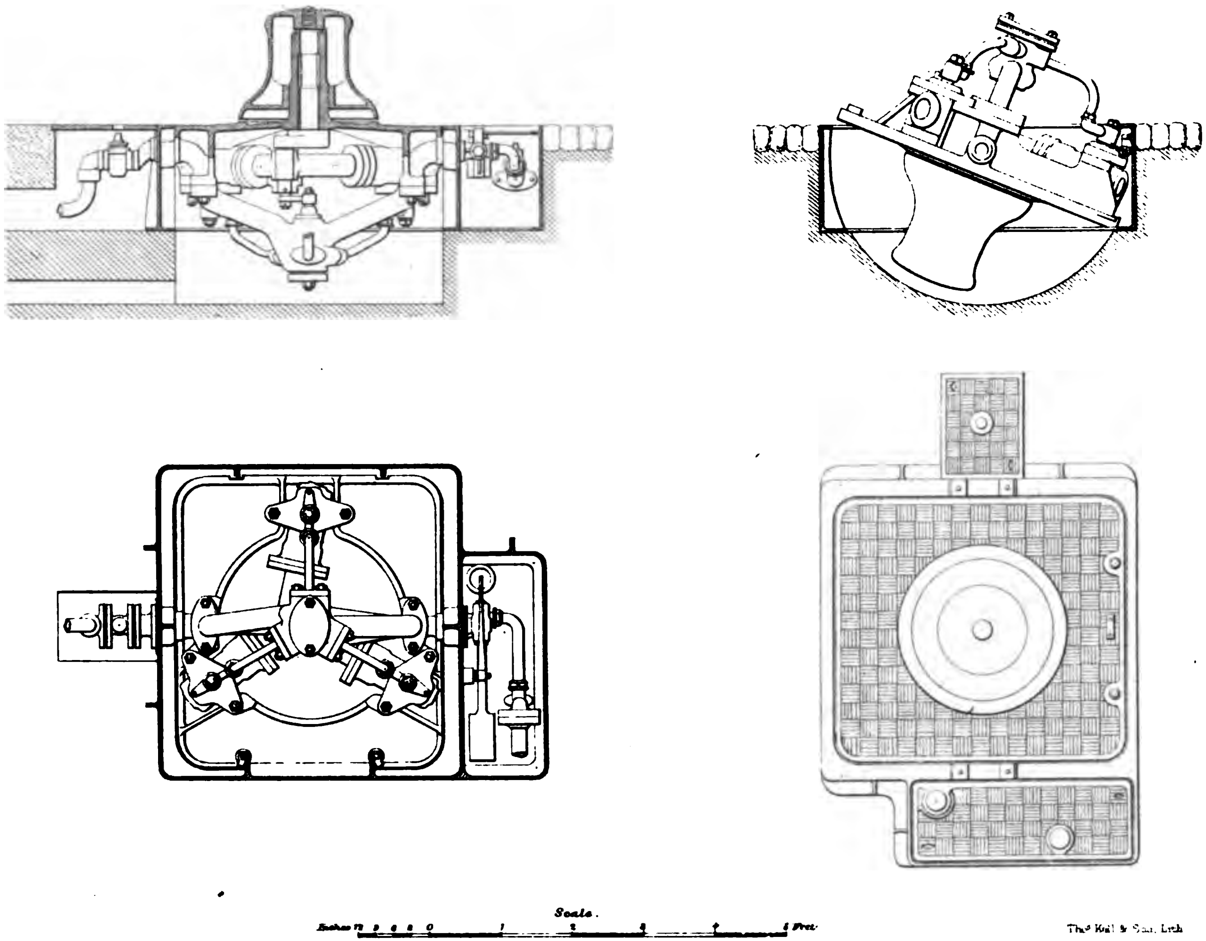
At the Lyric Theatre hydraulic stage machinery was introduced in the form of five sets of "bridges" (constructed by Messrs Clark & Bunnet) supported by hydraulic rams and placed towards the rear of the stage proper. Four of these "bridges" rose to the level of the stage floor (which is 17 feet 3 inches from the cellar floor), but the fifth and larger one could be taken 10 feet above the stage floor level. The loads for the four were 2 tons, and for the fifth 3 tons. There are two rams to each "bridge," 3¼ inches in diameter for the four front "bridges," and 4 inches for the larger one.

HYDRAULIC CAPSTANS.

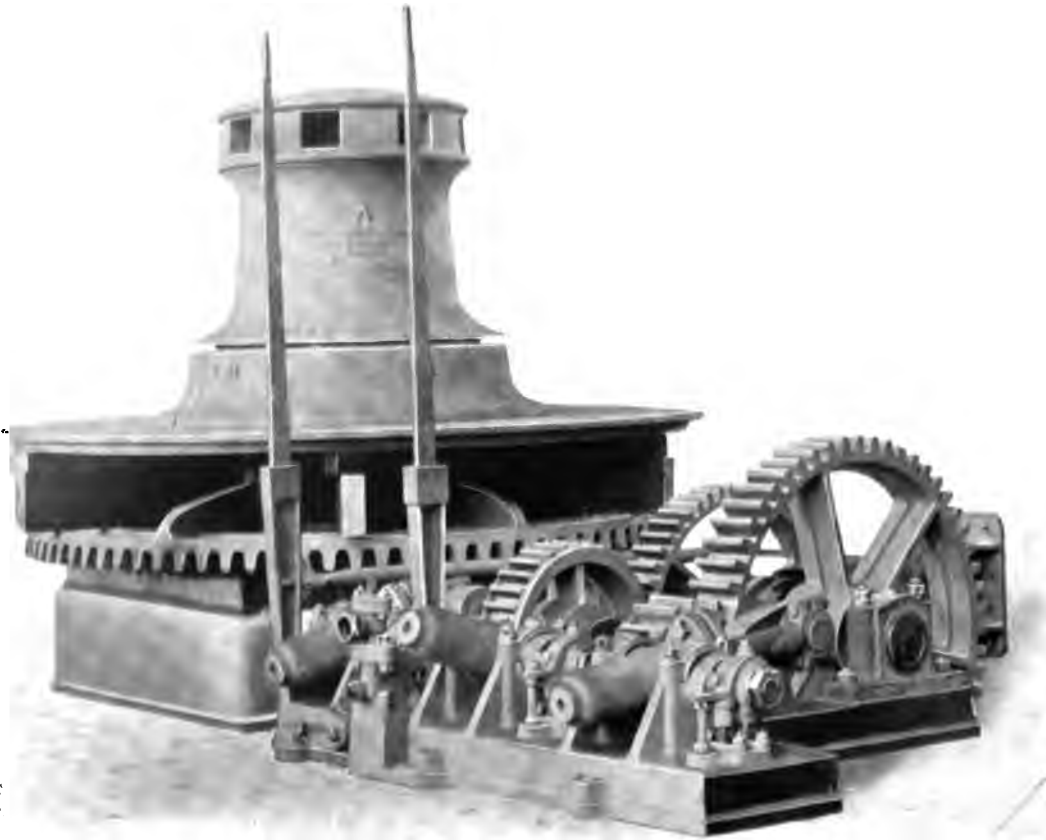
The production of a simple hydraulic rotary engine led to its application to capstans, several forms of which have been introduced. One is that made at Elswick, which may be termed the turnover hydraulic capstan, as shown by Plate 15. A bed-plate is hinged upon two trunnions, one admitting the pressure, and the other being used for the outflow of the exhaust water after it has passed through the working valve or valves. To the bed-plate is cast a pillar, through which the crank shaft is guided, and to the other end of which the capstan head is fixed. To the single crank, on which the three rams act, is attached a cross-rod communicating motion to a rotary valve, from which branch pipes convey the water to and from each cylinder. The trunnions of the bed-plate are carried on bearings attached to a cast-iron casing, which forms a framework for the capstan, and on which also is carried the working valve for regulating the starting and stopping of the capstan. This working valve is usually a mitred valve, to which a counter-weight and lever are attached, in such a manner that the counter-weight, when free, keeps the valve closed. To start the engines, the lever is pressed with the foot, thus

TURNOVER HYDRAULIC CAPSTAN.

FOR HAULING RAILWAY WAGONS.



Thos Kell & Son, Lith



ELSWICK HYDRAULIC CAPSTAN.

raising the weight which keeps the valves closed. When the foot is removed the valve is closed, and the action of the capstan is stopped. The capstan is so balanced on the trunnions that it can be easily turned over by one man. The advantages of this arrangement chiefly consist in the facilities that are afforded for examining and oiling the parts. The capstan can be worked in any position, so that its action can be readily seen and adjusted. The usual power given to working capstans is equal to a hauling power of about 1 ton on the rope, but smaller capstans than these are used where only one or two wagons are required to be moved at a time. The speed of the capstan can be varied from 2 or 3 revolutions per minute to upwards of 100 revolutions.

Plate 16 shows an Elswick hydraulic capstan of 11 tons hauling power for dock use. The engine, gearing, etc., are placed, of course, beneath the quay-level.

The introduction of hydraulic capstans into railway goods yards and other similar places, has proved of great advantage in expediting the operations of shifting trucks, making-up trains, and the like.

HYDRAULIC TRAVERSERS.

The transference of railway trucks or carriages from one line of rails to another is rapidly effected by traversers worked by hydraulic power. The expedition in making up trains, both goods and passenger, that results, has led to their extensive use. The construction simply consists in detaching a length of the line, sufficient for the carriage or truck to stand on, and by suitable framing beneath to support it on rollers resting on rails. These rails are laid between the two lines to be served by the traverser, and they enable the frame, with the carriage or truck on it, to be rolled from one line to the other. This can be done by placing a hydraulic cylinder and ram with multiplying sheaves in a pit adjoining, and by con-

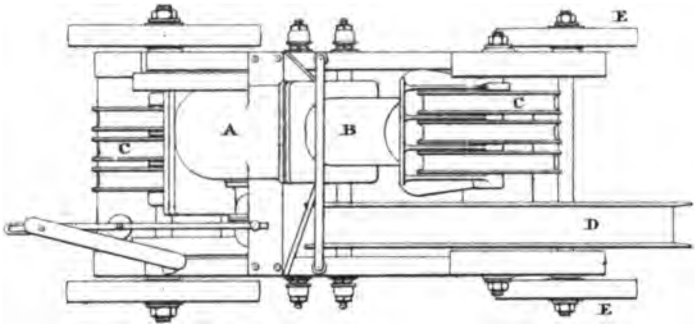
necting the chain or cable to the traverser, a short stroke of the ram produces a long run of the traverser. At the new harbour at Frankfort-on-Main an installation of hydraulic power was carried out by Mr W. H. Lindley, the engineer to the magistracy of that town, and the author inspected this installation in 1888. Traversers were used with a travel of 44 metres between centres of rails, and this long run involved the employment of three-cylinder engines, the power being conveyed by cables passing over a series of sheaves arranged in straight lines, by which no undue wear and tear of the cables arose. A trial of one of these traversers gave 220 seconds as the time occupied in the several operations of bringing the traverser from one line to the other, hauling a truck on to it, transferring it to the other line (44 metres away), and hauling the truck off. A trial was made by running the traverser a longer distance than between these two lines (the range of travel extending to more than two lines of rails). A wagon with a load of 15,500 kilogrammes was put on the traverser, which was run backwards and forwards through a total of 59 metres. The engines made 100 revolutions and used 310 kilogrammes of water.

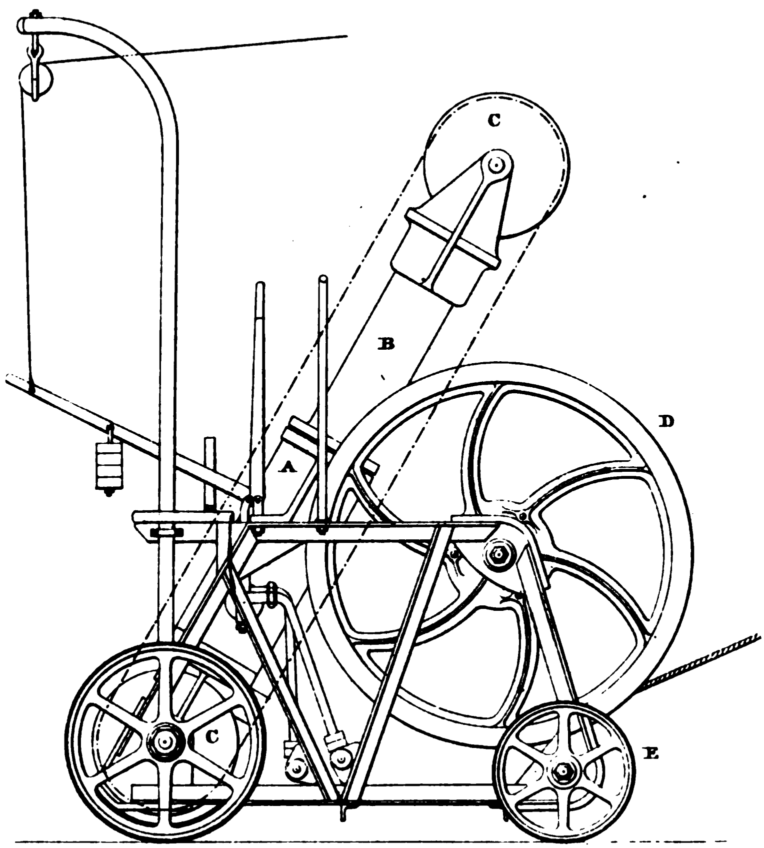
MOVABLE JIGGER HOIST.

A movable jigger hoist is shown by Plate 17. This machine consists of a hydraulic cylinder A, with a ram B, and multiplying sheaves C C. The lifting rope or chain passes over the large drum D, and the chain for communicating the power from the cylinder passes over a smaller one which is attached to it. The lifting slide valve is fixed to one side of the cylinder, and is worked by a man standing on a platform above the valve. Valve gear can be fitted to the machine (as shown in the figure) by which the jigger can be worked by a man standing on a ship's deck, and looking directly into the hold. The machine itself remains on the quay, thus dispensing with one man. It

MOVEABLE JIGGER HOIST,

TO LIFT 15 CWT.





Scale: ⅜ Inch = 1 Foot.

Inches 12 9 6 3 0 1 2 3 4 5 Feet.

is mounted on a wrought-iron frame, carried on four wheels E, so as to allow of its being moved from place to place. The water is conveyed to the machine from the main through jointed pipes, which allow a considerable amount of travel of the jiggers without alteration of the pipe connections. The pressure and exhaust connections on the jiggers are shown, with caps for protecting the joints when the machine is not in use. These jiggers are of varying powers, according to the purpose to which they are to be applied, whether for lifting sacks of corn, or light jute bales. They work with great rapidity, making from four to five lifts per minute from the hold of a vessel.

HYDRAULIC WAGON DROP.

In the arrangements for charging blast furnaces, a wagon drop is generally employed for lowering the charges into the furnace, the downward movement being controlled by a brake applied to the shaft on which are fixed the sheaves for the chains or wire ropes. Sir Thomas Wrightson has successfully applied water as the controlling agent of the brake, and he described this arrangement at a meeting of the Iron and Steel Institute. Fig. 32 shows the means by which water in this case is utilised as a hydraulic brake. A cylinder A (10 or 12 inches diameter) has a stroke the same as the rise or fall of the cage, which is suspended from the piston-rod D, at the other end of it being the piston C, working in the cylinder. At the top of the cylinder is a small supply tank E, fitted with a self-acting ball-cock, to keep the same always supplied from the nearest water main. A small adjustable hole F in the cover communicates with the inside of the cylinder, to ensure that it is always full of water, and another small hole G in the piston allows any air which may accumulate under the piston to pass to the upper part of the cylinder, where it escapes into the tank by the hole F.

A pipe H connects the top with the bottom of the cylinder,

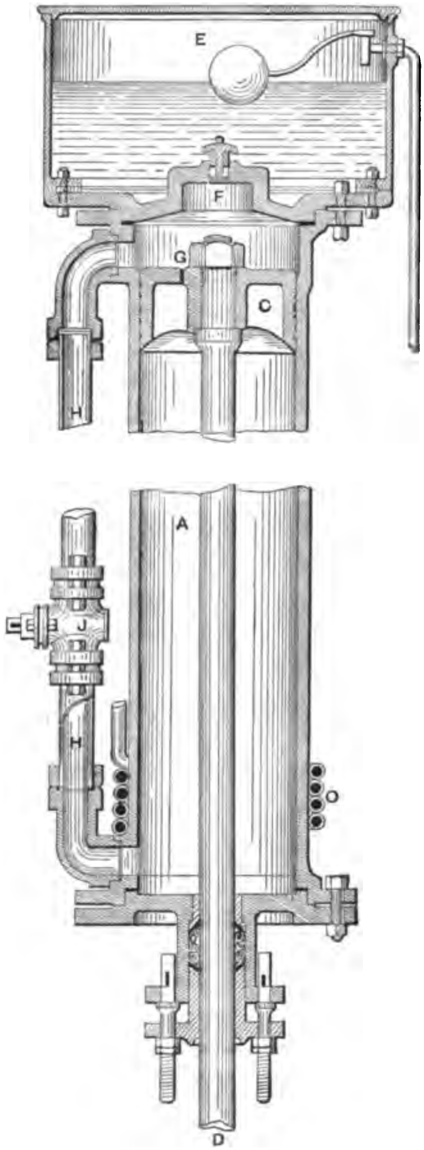


Fig. 32.

through an ordinary water-cock J, which is controlled by a

weight-bar and lever. A catch lever is placed alongside the valve lever, and serves to lock the cage as it comes to the top of its stroke. This holds the cage while the wagon runs on. When the cage with the wagon on is required to descend, the catch rod is liberated, and then the valve handle is lifted. By the opening of this valve J the water passes from the bottom to the top of the piston, thus controlling the descent of the cage with the greatest nicety to any speed the attendant may choose. When the cage is at the bottom, a self-acting stop is removed by the action of the cage touching the ground, which allows the wagon to run off at the lower level. The cage being then lighter than the counter-weights, is drawn up again, the water in the cylinder, during the ascent, returning from the top to the bottom of the piston. When the cage arrives at the top of its stroke, it locks itself, and is then ready for another wagon to be run on.

The bulk of the water passes and re-passes through the cock J, but on account of the area of the piston being less on the lower side than the upper (by the area of the piston-rod on the lower side), the water at the top, displaced as the piston rises, cannot find room at the lower side of the piston, and will, therefore, find relief by a portion (equivalent to the cubical contents of the piston-rod) passing through the small hole in the cylinder cover into the supply tank. In the same way when the piston again descends, there would be an equal deficiency in the water passing from the bottom to the top side of the piston; this is compensated for by the same amount of water re-passing through the hole in the cover. By this means the cylinder is always kept full of water, which is essential to the successful working of the apparatus. It will be observed that the same water is used over and over again, and that the ball valve in the tank is merely to supply any loss from evaporation or leakage. The small pipe O, encircling the cylinder, is for the admission of steam in frosty weather to prevent the freezing of the water. This comes from the nearest steam or exhaust pipe, and after coiling a few times round the lower part of the cylinder, passes up to the top tank alongside of the connecting pipe.

Sir Thomas Wrightson informed the author in December 1902 that the centre balance crane had been at work for twenty years, with most satisfactory results, at the works of the North-Eastern Steel Company at Middlesbrough.

Plate 18 shows a jigger which the Hydraulic Engineering Company have supplied for lifting the material excavated in the construction of the "Tubes" for the Brompton and Piccadilly Circus Railway, and for the Charing Cross and Hampstead Railway. The load to be lifted is from 35 cwt. to 2 tons, and the stroke of the ram and the multiplying power of the pullies enables the load to be raised heights varying from 90 to 130 feet.

CRANES.

In all the designs for hydraulic cranes the principle employed is that of using the direct thrust of a ram or piston through a short stroke, and multiplying the stroke by carrying the lifting chain over a series of sheaves. In general, the cylinders and machinery are placed horizontally in a chamber underground. In some cases the lifting cylinder is placed vertically, and is made to form part of the pillar of the crane, as is shown by Plate 19, fig. 1, which represents a goods station crane for a lofty goods shed, the pillar being carried by top and bottom bearings. The lifting cylinder is placed in the pillar of the crane, to which pillar the working valve is fixed, the water entering and escaping, through the pivot as shown by fig. 2.

A form of station crane is shown by Plate 20, which represents one of the cranes originally erected at the goods station of the North-Eastern Railway at Newcastle-on-Tyne.

When the load to be raised becomes very great (100 tons or so), it is better to substitute some other arrangement for that of chains. In the case of a large crane which Sir William Armstrong, Mitchell & Co. erected at the Royal Italian

HYDRAULIC ENGINEERING COMPANY'S JIGGER.

HYDRAULIC GOODS CRANE.

PLATE 19.

Fig 1.

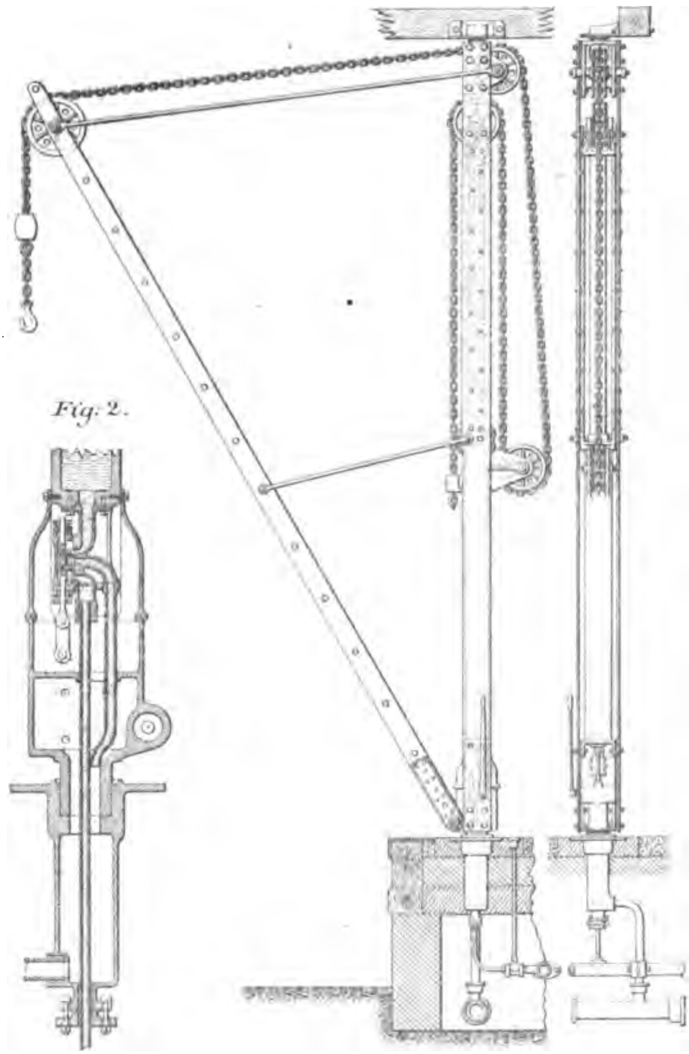
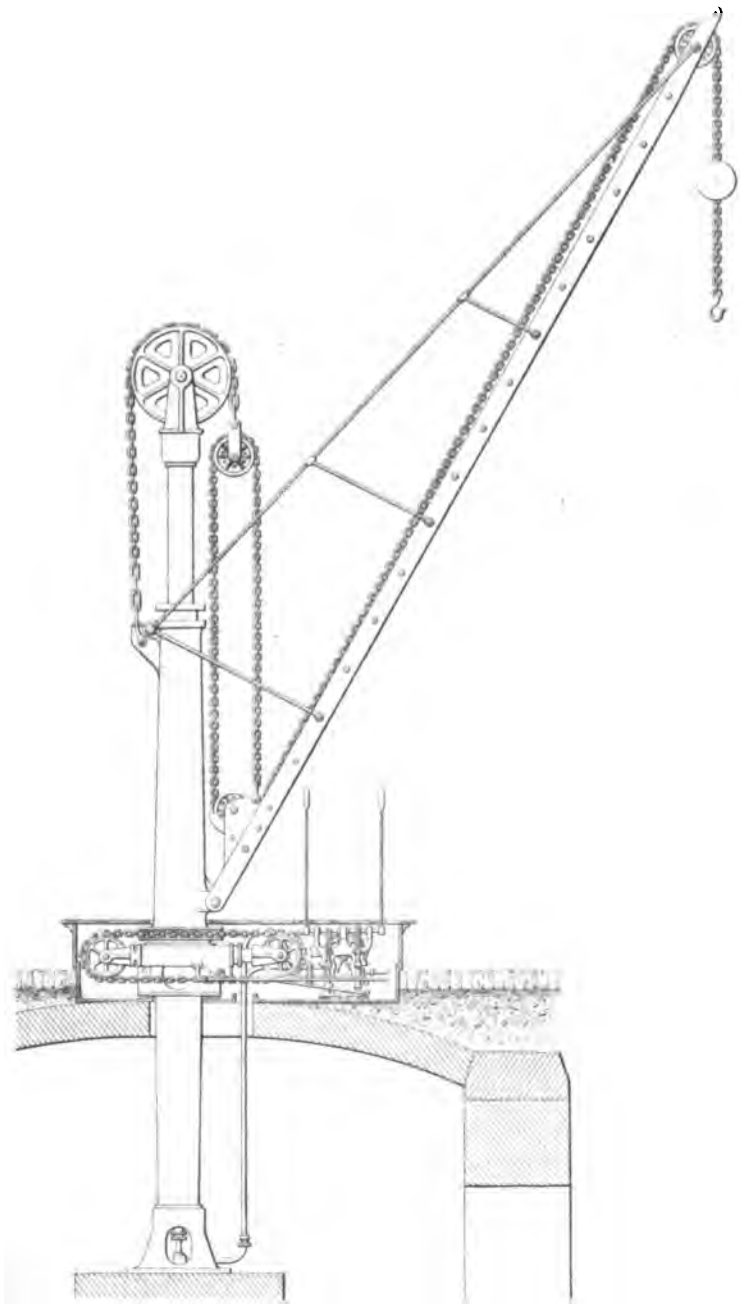


Fig. 2.



Arsenal at Spezzia, the lift is performed by the direct action of a piston contained in an inverted cylinder suspended in gimbals from the head of the jib, as shown by Plate 21. This crane is capable of lifting 160 tons through a range of 40 feet. It is carried upon a ring of live rollers supported by a pedestal of masonry, and the slewing is effected by a hydraulic engine applied to a pinion gearing into a circular rack. The jib projects 65 feet from the centre of rotation, and its height above the quay level is 105 feet. If the crane is used to lift much lighter loads than the maximum, a chain is employed, which is raised and lowered from a cupped drum, worked by the slewing engine.

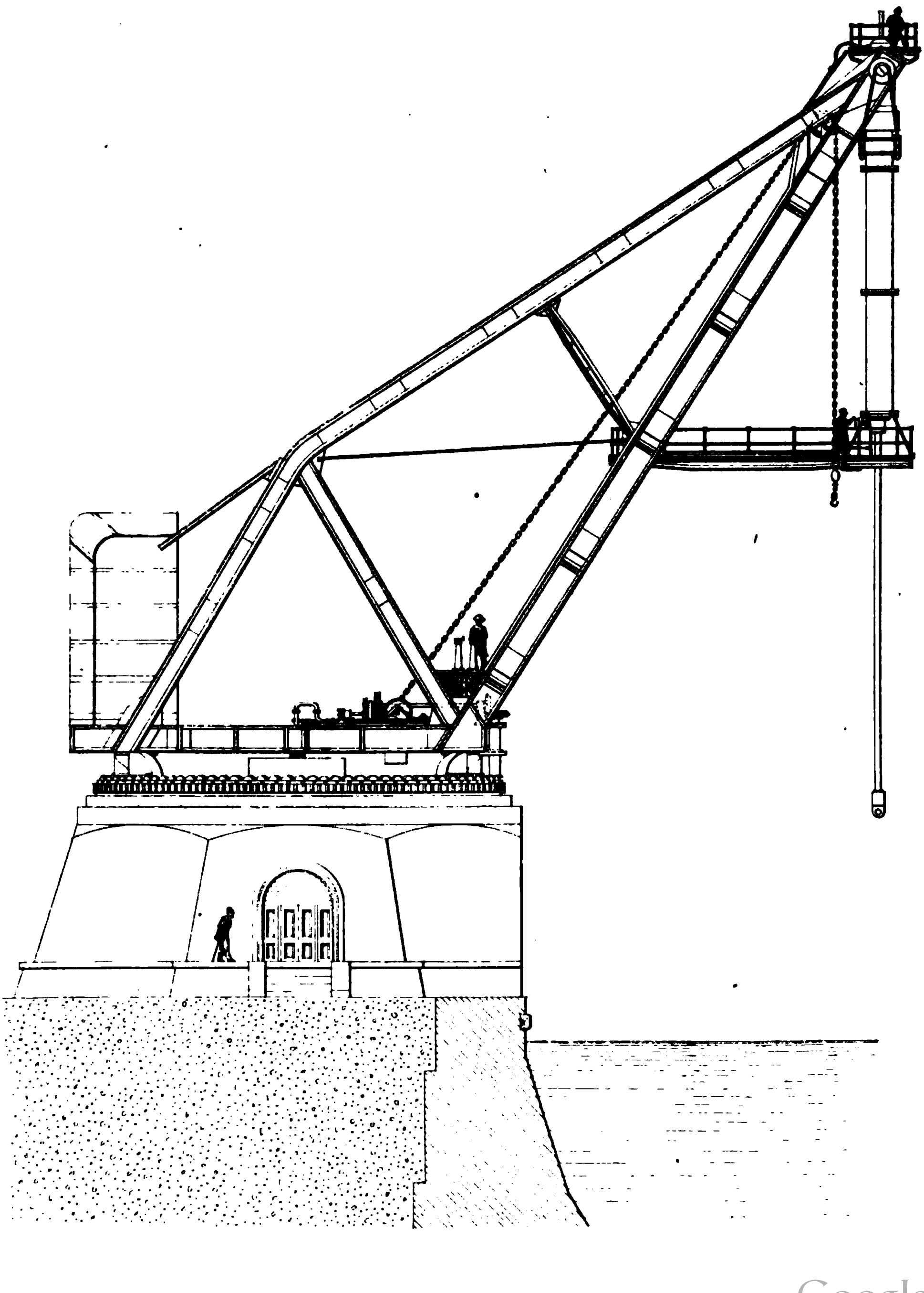
Plate 22 shows an Elswick hydraulic crane for storing coal, etc. It has a maximum rake of 75 feet, there being a travelling movement along the jib to the extent of 65 feet. The total area commanded by the crane is 17,500 square feet, giving a storage of about 400,000 cubic feet. All the motions of lifting, turning, traversing in or out, and opening and closing the doors at the bottom of the box, are commanded from the cabin on the front of the crane pillar.

Mr Percy G. B. Westmacott devoted much attention at Elswick, many years ago, to designing a crane for discharging coal that could be moved on a line of rails to enable the crane to command ships' hatches which are in ever-varying positions.

The first movable hydraulic crane was designed by Mr Westmacott, and erected by the Elswick firm at the Bute Docks, Cardiff. A description of this was given by Mr M'Connochie at the Cardiff meeting of the Institution of Mechanical Engineers in 1884, and is shown by Plate 23. The shipping of coal direct from the trucks had previously been carried out by fixed hydraulic cranes. It was, however, found that the work could not be done rapidly enough, as the fixed cranes could only load into one hatchway of a ship, since the positions of the hatchways in steamers varied so much that the cranes could not be placed to suit different vessels. Movable cranes were decided upon to obviate this hindrance

to rapid working; but as the cradle or platform on which the truck was lifted required a pit in the line of rails for its reception, a crane could only pick up wagons at one point. To meet this difficulty, Mr Westmacott designed the coaling cradle C, shown by fig. 1. It consists of a light platform suspended by chains capable of being placed in any position upon a line of rails. The platform is permanently hung by chains from an anti-friction swivel S (shown to a larger scale in figs. 4 and 5), which enables a man to turn the cradle with a loaded wagon on it, thereby dispensing with turntables.

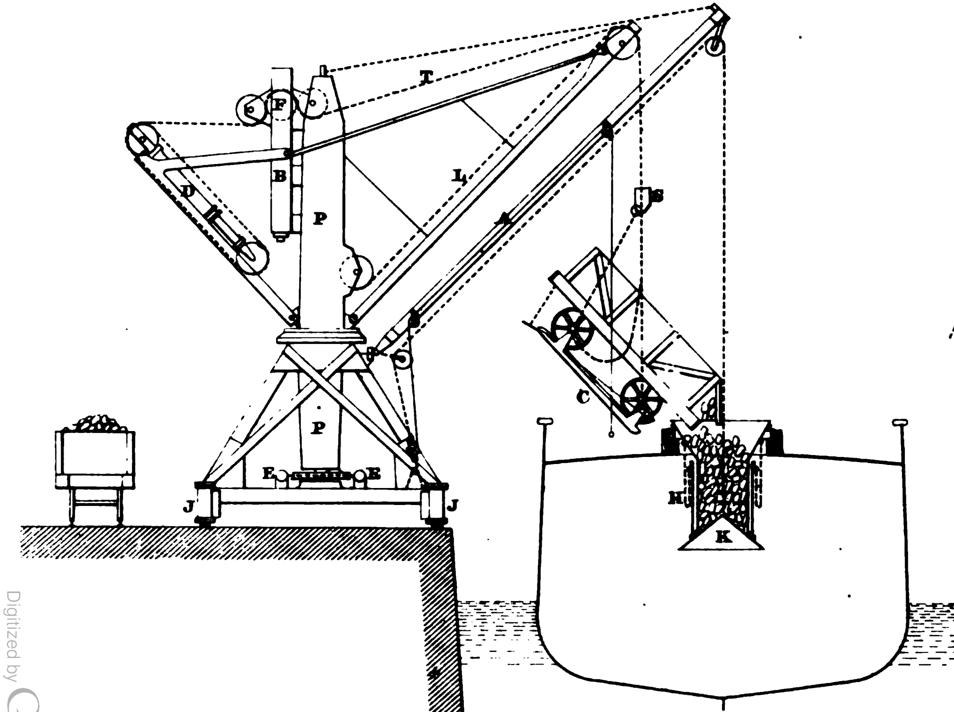
The crane is carried on a nearly square wrought-iron pedestal, which runs on four wheels upon a line of rails of 24 feet gauge. There are also four lifting jacks J J, one at each corner, which take the weight when the crane is at work. The pillar P P consists of two flat plate girders which revolve in bearings at the top and bottom of the pedestal. There are three hydraulic cylinders for lifting and tipping; the first is placed between the girders of the pillar for lifting the load by means of the chain L, the two ends of which are made fast to the swivel attachment S. The second, D, is for tightening the tipping chains T, and the third, B, is for effecting the tipping, by making a bight in the tipping chain (as shown at F), while the cylinder D is locked by its valves. The pillar is turned by two horizontal hydraulic cylinders, E E (one on each side of the pillar), fixed to the pedestal, and working a chain which passes round a drum at the foot of the pillar. All the motions are readily controlled by one man in a valve-house fixed to the pedestal (not shown on the Plate). Two such houses are provided, on opposite sides of the crane, so that the man can use whichever is most convenient for watching the operations. The pressure water is conveyed to the crane by movable jointed pipes, which can be attached to hydrants placed at convenient distances on the hydraulic mains along the quay wall. There is an auxiliary or anti-breakage crane, A, on the side next the dock, for working a hopper, H, resting on the deck of the ship. This hopper (designed by Mr Charles



ELSWICK HYDRAULIC CRANE FOR STORING COAL.

MOVABLE HYDRAULIC CRANE.

Fig: 1.



SIDE ELEVATION, SHOWING MODE OF TIPPING.

Scale 1/200th

Feet 10 5 0 10 20 30 40 50 Feet

Fig: 4.

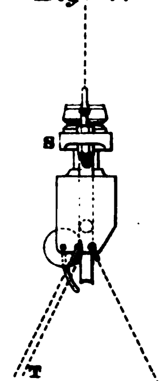
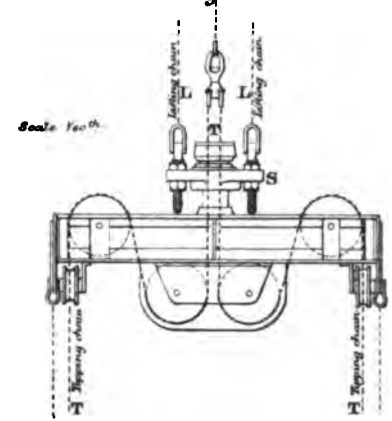


Fig: 5.



SWIVEL ATTACHMENT.

Fig: 2.

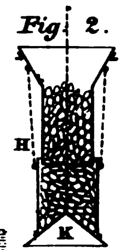
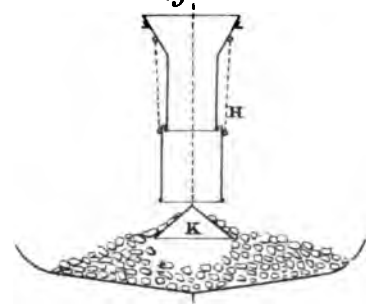


Fig: 3.



TELESCOPIC HOPPER.

Thos Kell & Son, Lith.

L. Hunter, of the Bute Works) has a telescopic throat of square section, which is closed by a pyramidal bottom, or valve, K, held up by the auxiliary crane A. The object of this is to allow the first few truck-loads of coal to be lowered gently to the bottom of the hold, so as to lessen the breakage of the coal (as shown in figs. 1 and 3). When not in use, this crane can be swung to the side, out of the way. A wagonful of coal can be shipped in from 2½ to 3 minutes.

To avoid the breakage of the coal by discharging it into coal ships by shoots direct from the coal trucks, many mechanical arrangements have been used, the most perfect of which are the hydraulic coal-hoisting machines that were introduced many years ago by the Armstrong firm. In order to minimise the breaking of the coal, it is desirable, as before stated, to form a heap in the hold of the ship by lowering some coal at the outset, either by a hydraulic crane or otherwise, and afterwards to provide for the discharge of the bulk of the coal slowly upon this heap, instead of delivering it with a rush. The Elswick firm arranged an apparatus to meet these requirements, and is applicable to low-level railway and flat-bottom wagons. The wagon is lifted upon a cradle resting on the top of a hydraulic ram, the coal being tipped into a shoot (large enough to hold a wagon-load of coal) which rises or falls, to meet the varying height of the deck, by connecting the shoot with the cradle, which ensures the right level being obtained. To regulate or stop the flow of the coal in the shoot, a pair of doors are fixed across its mouth. The coal is discharged by tipping the wagon by a hydraulic press, mounted on trunnions, which travels with the cradle and raises the back of the platform (which is hinged in front) to the desired inclination. The various movements are governed by valves, worked by a man stationed on an elevated platform commanding a view of the operations. The wagons are brought to, and removed from, the coal-tipping apparatus by means of hydraulic capstans, turntables, or traversing machines, according to circumstances. A great number of coal-hoisting machines, based on this

principle, are in use wherever the expeditious transference of coal from wagons to ships is requisite.

The same firm have an anti-breakage crane which is in general use. This has a square iron bucket which holds a ton of coal. It is made hopper-shaped, with a hinged flap for discharging at the bottom. It is suspended from a light jib crane fixed at one side of the tip frame, and having in the hydraulic tips, hydraulic lifting and turning motions. In commencing the loading of a ship this bucket is filled from the shoot, then lowered to the bottom of the hold, and emptied by pulling up the bolt that secures the flap door. This process is repeated until a conical heap is made up to the shoot, which is then allowed to discharge freely.

Plate 24 shows a movable hydraulic crane for shipping coal direct from trucks into ships. The crane consists of a heavy pillar revolving in a built pedestal having an archway large enough to pass locomotives and box wagons. The lower part of the pillar is carried in a footstep attached to the bottom of the pedestal above the archway, and the upper bearing of the pillar is formed by the top of the pedestal. The pillar carries a jib pivoted on a pin at its heel, the rake or radius of which can be varied within wide limits by a hydraulic cylinder and ram placed in an inclined position at the back of the pillar, this ram being connected with the head of the jib by links or girders. The turning of the pillar and jib is effected by hydraulic cylinders placed on the back of the pillar alongside the luffing cylinder, and acting on a chain which fits into a cupped drum round the top of the pedestal. The lifting machinery is placed within the cheeks of the pillar, and consists of a hydraulic cylinder with ram, multiplying sheaves, etc., and there is, in addition, a tipping cylinder which is placed between the turning cylinders on the back of the pillar, this cylinder acting on the tipping chain by which the rear end of the wagon is tipped up. Attached to the lifting and tipping chains is a cradle for receiving coal trucks of either "end" or "bottom door" pattern. This cradle fits into a seat which can be placed on

CRANE FOR LOADING COLLIERS.

the lines of rails at any point without the quay being in any way cut up.

The power is supplied by a hydraulic engine placed in the pedestal connected to the travelling wheels by shafts and gearing.

Plate 25 shows a number of Elswick movable hydraulic cranes varying in power from $2\frac{1}{2}$ tons to 10 tons. The lifting cylinder is placed in the pillar, which, with the jib and counter-weight frame, is carried in a wrought iron arched pedestal, the upper part of which forms the bearings for the pillar, and contains the turning cylinders. The archway is of sufficient size to allow locomotives to pass under. The valves are operated from a driver's box on the side of the pedestal. The cranes move on four wheels fitted with hand-travelling gear, and the connection with the hydrant on the hydraulic main is made by sliding or jointed pipes at any desired position.

Plate 26 shows an Elswick fixed coal hoist, the lifting machinery consisting of a ram and cylinder with multiplying sheaves placed on one side of the framing and connected to the cradle by chains passing over sheaves on the top of the framing.

Plate 27 shows an Elswick movable hydraulic coal hoist, the lifting machinery consisting of a ram and cylinder with multiplying sheaves placed on the back of the framing and connected to the cradle by chains passing over sheaves on the top of the framing. It is on wheels, which allow it to be moved to and fro on the quays to suit the hatchways of vessels, there being a number of lines on the quay opposite to one of which the hoist can be placed. These lines radiate from turntables communicating with the full and empty roads. These hoists are principally of service to enable two hoists to be worked into the same vessel, as owing to the constantly varying positions of hatchways two fixed hoists would but very rarely be capable of loading into the same vessel. The moving of the hoist is effected by a hydraulic engine and gearing.

Hydraulic coal hoists are employed at Goole Docks for shipping coal from compartment barges brought down the Aire

and Calder Navigation. These boats are brought down the canal in long strings articulated together. On reaching the docks they are divided up. The compartments or barges are floated one at a time on to the submerged cradle of one of the coal hoists. The cradle is then lifted until the barge is clear of the water, when clips are made fast to the rear of the barge securing it to the cradle. The lifting is then continued and the barge lifted to the necessary height, when it is turned over sideways and the coal falls into a shoot by which it is conveyed to the hold of the vessel. The empty boat is then turned back to the horizontal position, the cradle lowered and the boat floated off. Each barge holds from 25 to 35 tons of coal.

The lifting of the cradle is effected by direct-acting hydraulic cylinders placed vertically above the cradle having pistons connected to the cradle by piston rods. The tipping was, in the first hoist, effected by rotary hydraulic engines and chains, but in the later hoists it is done by cylinder and ram with multiplying sheaves acting on chains. There are in all three hoists, the first being erected in the year 1863, and the third in the year 1900.

HYDRAULIC MACHINERY ON BOARD SHIP.

The Elswick firm applied hydraulic davits and derrick hoists on board H.M.S. "Vulcan" for lifting with ease and quickness the torpedo boats, launches, and steam pinnace. To deal with the torpedo boats there are two large hydraulic davits with a lifting power of 20 tons, and a radius of 38 feet, the pillar being placed so that the jib commands 29 feet beyond the side of the vessel. The lifting machinery is in the pillar, and is worked at a pressure of 1000 lbs. per square inch. The slewing motion is obtained by means of two cylinders (with 16-inch rams) placed vertically beside the pillar, and has a range of 250°, which is sufficient to enable a boat to be picked up from alongside and placed in almost any position on deck.

ELSWICK MOVABLE HYDRAULIC CRANE FOR COAL LOADING.

ELSWICK FIXED COAL HOIST.

ELSWICK MOVABLE COAL HOIST.

In addition to the torpedo-boat davits, hydraulic lifting, topping, and slewing gear are fitted to a derrick to deal with launches up to a weight of about 10 tons. The lifting arrangements are similar in principle to those employed for the davits, the cylinders being placed vertically near the heel of the derrick. The topping machinery consists of a cylinder (telescopic, to economise space) with a plunger, etc. The load of 10 tons can be lifted 25 feet from the water level at the rate of 90 feet per minute, and the topping of the derrick with the load can be done at the rate of 20 feet per minute.

The same firm have recently fitted hydraulic derrick hoists on board three battleships and three large cruisers, for H.M. Government for lifting boats up to 20 tons weight, and are now about to fit similar gear on the five battleships of the "King Edward VII." class, the arrangements of the gear being almost exactly the same as for the derrick hoist of the "Vulcan," except that the power is 20 tons instead of 10 tons.

Hydraulic power is now being applied to perform the deck work on board the larger steamships, instead of the steam appliances which were previously used. In discharging a ship's cargo, the expedition afforded in all large docks by the employment of hydraulic cranes and other appliances has not until quite recently been met with corresponding facilities on board ship.

On board steamships the accumulator can be dispensed with, as the power required to work hydraulic apparatus under these circumstances is generally produced, and communicated direct to the machine, by motors which are capable of working at very high speeds, and of developing in a small compass a large amount of energy.

Direct-acting cylinders, working upon the single crank, have been applied by Sir W. G. Armstrong, Mitchell & Co. to ship-capstans up to 5 tons power. In these the bed-plate is fixed, as it would be too unwieldy to use in the form of the turn-over arrangement already described for docks and yards. The capstan-head is in some instances

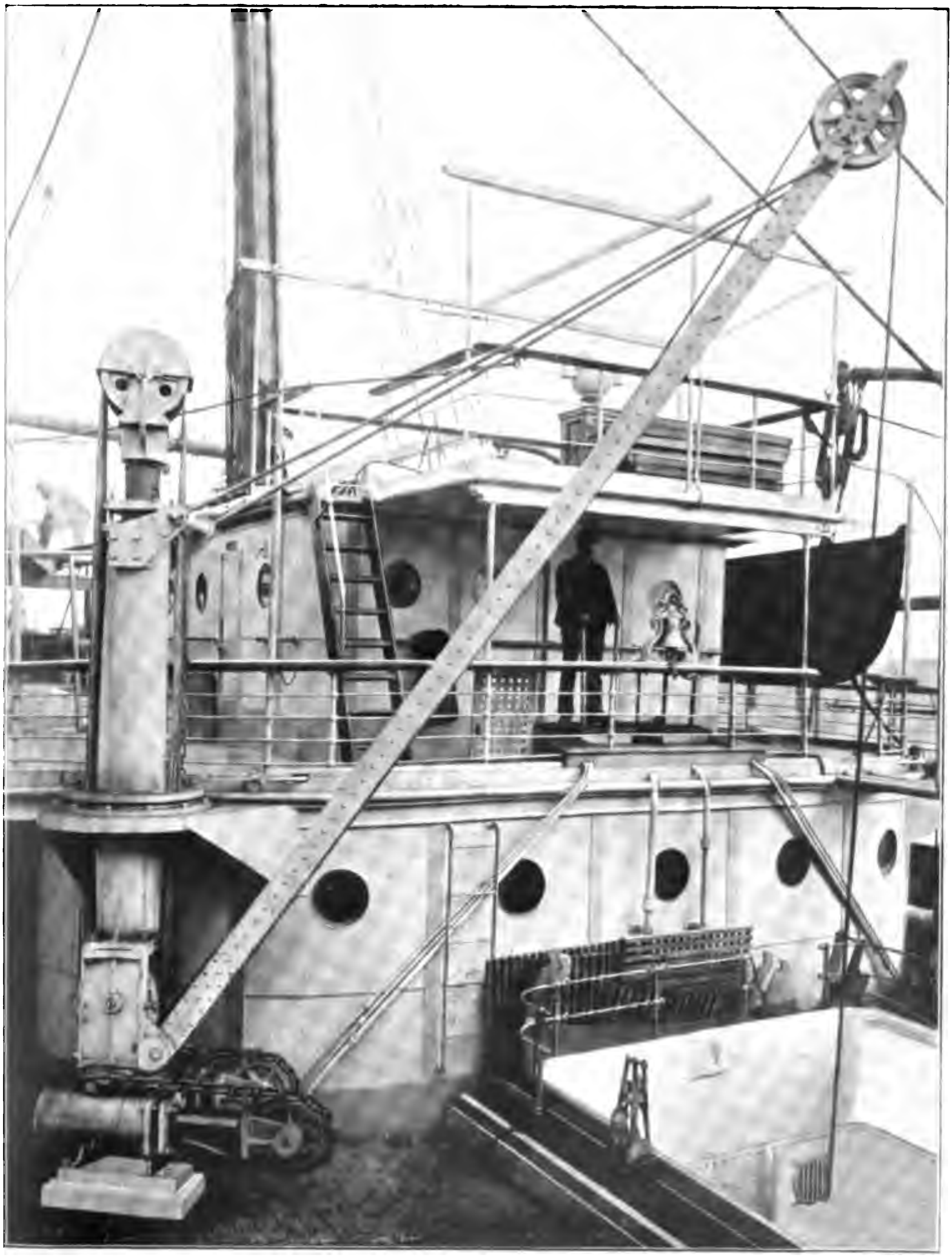
arranged with two diameters; the larger being for the lighter power, and the smaller for the heaviest strain upon a hawser. The capstan-head is also provided with handspikes and rack, so that, if desired, it can be worked by hand as an ordinary capstan. A separate hydraulic engine (usually with three cylinders) produces the power which is conveyed from it to the capstan by means of gearing.

Hydraulic power is also employed to work the steering-gear of ships. It is necessary that the power applied should increase in proportion to the angle at which the rudder is moved over, and that the machinery should yield under any excessive strain, so as to allow the rudder to fly amidships, but to return after the strain has passed away. The valve for controlling the steering-gear should be placed where it can be worked under the eye of the officer of the watch.

Plate 28 shows one of the Elswick cranes on board ship, the lifting cylinder forming the pillar, with the slewing cylinders at the base.

HYDRAULIC POWER APPLIED TO BRIDGES.

The first application of hydraulic power to bridges was in 1852, when the Forest of Dean Railway Company constructed a hydraulic swing-bridge over the river Severn. A double leaf swing bridge of timber was constructed and worked by hydraulic power about the same time at the Birkenhead Docks. Each leaf of this bridge had a central hydraulic press of sufficient power to lift the leaf, and acting at the same time on the pivot upon which the bridge revolved. The tail end of the bridge was fitted with two rollers, which were brought in contact against an upper rail, so that, as the tail end was lighter than the nose end, when the bridge was lifted from its bearings the rollers at the tail end were brought against the rail, and the pressure being continued on the centre press, lifted the bridge clear of the masonry. The swinging of the



ELSWICK HYDRAULIC CRANE ON BOARD SHIP.

bridge was effected by means of a hand rack and pinion, but as the bridge was carried on a water pivot it was easily worked. The bridge rested on masonry supports when not at work. The first operation of lifting the bridge off its bearings was performed in a few seconds, by turning the water from the accumulator into the centre press.

In some examples of the application of hydraulic power to swing-bridges a single press forms the water-bed. In others the ram is not attached to the bridge, but the end of it is made of a cup-shape, in which revolves the pivot that is attached to the bridge. In some swing-bridges the tail end is made light. In others the tail end of the bridge is made heavy, so that when the bridge is lifted the nose end is raised, the tail end resting upon a rail below the roller path. Occasionally it has been found advisable (as a stand-by) to have a means of working the bridge by hand-power. This is done by using the centre press as a solid pivot, the ram resting upon the bottom of the cylinder, and the bridge revolving in a cup formed in the upper part of the ram. By means of presses applied to the tail end of the bridge and worked by hand-pumps, it can be lifted or lowered to clear the bridge from its resting-blocks, and to leave it free to revolve.

Plate 29 shows a "hydraulic swing-bridge" constructed by Sir W. G. Armstrong, Mitchell & Co. This bridge crosses a clear opening of 100 feet, and is adapted for both road and railway traffic. The clear width of roadway between the kerbs is 23 feet. The footways are on the outside of the main girders, and have each a clear width of 4 feet 10 inches. The bridge is designed for a rolling load of 1¼ tons per foot run on each line of railway, and for a concentrated load of 60 tons on four wheels. The main girders are of the triangular or braced construction, the cross-girders for carrying the roadway being fixed to the main girders at the foot of each system of triangulation, with longitudinal girders between the cross-girders under each line of rails. The bridge is lifted from its bearings (preparatory to being

turned round) by a hydraulic press acting on a wrought-iron bearing-girder fixed to the under side of the main girders. The turning motion is effected by two hydraulic cylinders acting, by means of chains, on a turning drum fixed to the under side of the bridge. A hand-pump is provided for use, in case the pressure from the main is not available. Should the centre press become disabled, provision is made for tilting the bridge from its bearings, by lowering the rear end wedge-resting block, hand-presses being provided for this purpose.

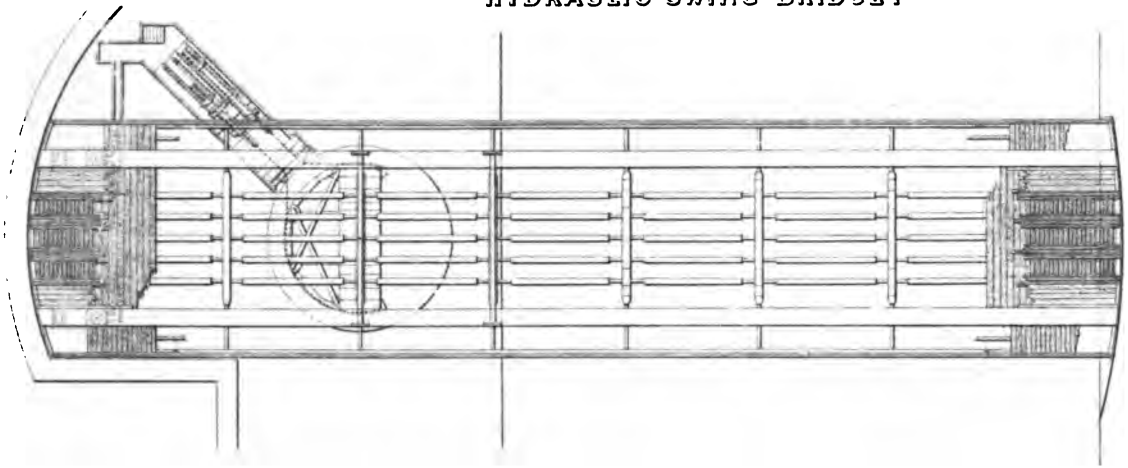
Another form of swing-bridge to which hydraulic power is applied is that which rests upon a circle of live rollers on a permanent roller path. The bridge is made to revolve either by means of one or more rotary hydraulic engines, placed on the centre pier within the circle of rollers, or by means of reciprocating acting rams and chains attached to the drum in the centre. The ends of each main girder are blocked by hydraulic presses after the bridge is closed.

The railway bridge over the river Ouse at Goole was described by Lord Armstrong when President of the Institution of Mechanical Engineers in 1869, and is shown by Plates 30 and 31. This bridge carries a double line of railway across the river Ouse, by means of three wrought-iron plate-girders, which, for the swinging portion of the bridge, are 250 feet long and 16 feet 6 inches deep in the centre. Plate 30 is a vertical transverse section at the centre pier, showing the engine-room and accumulator situated within it. Plate 31 is an enlarged section of one-half of the engine-room. The centre girder of the three is strengthened, and rests on an annular box girder A A, 32 feet in diameter, which forms the cap of the centre pier. This cap rests on the top of six cast-iron columns 7 feet in diameter, which are arranged in a circle and form the centre pier. A centre column B B, also 7 feet in diameter, contains the accumulator, and is attached to the others by cast-iron stays which support a floor. On this the steam-engine, boilers, etc., for producing the hydraulic power are fixed.

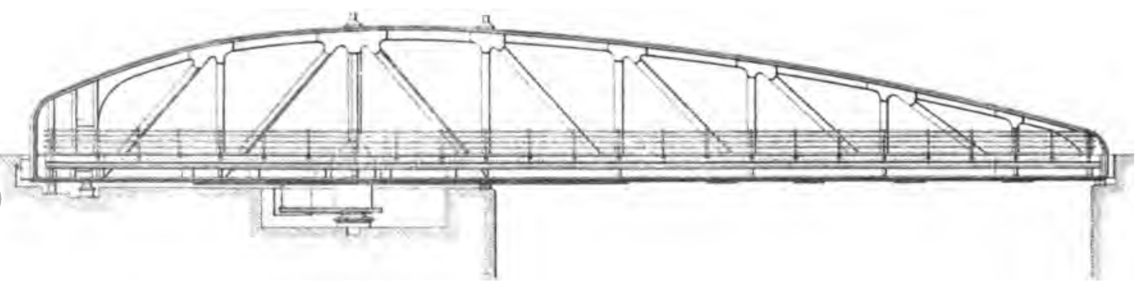
The weight of the swing-bridge is 670 tons, and it rests

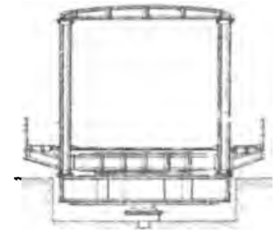
PLATE 29.

HYDRAULIC SWING BRIDGE.



SECTION THROUGH CENTRE PRESS.





Scale.

entirely on a circle of 26 conical live rollers E E. These are 3 feet in diameter, with 14 inches width of tread, and run between the two circular roller-paths D D, which are 32 feet in diameter and 15 inches wide.

The turning motion is communicated to the bridge by a bevel wheel H, which gears into a cast-iron circular rack G, bolted to the outer circumference of the upper roller path. A steel pin J, supported in the lower roller path, carries the bevel wheel. This is driven by a pinion connected by intermediate gearing with a three-cylinder hydraulic engine (in duplicate) placed at K K, which exerts a force of about 10 tons at the radius of the roller path. The engines work at 40 revolutions per minute, with a water-pressure of 700 lbs. per square inch. The power is obtained from a pair of 12 h.-p. steam-engines fixed (as before stated) in the engine-room formed beneath the centre of the bridge. Water is delivered into the accumulator C, which has a ram 16½ inches in diameter and 17-feet stroke, and is loaded with a weight of 67 tons.

To secure a solid roadway, and a perfect continuity of the line of rails, an arrangement of gearing, shown by Plate 32, figs. 1, 2, 3, and 4, is used. By this, each extremity of the bridge is slightly lifted by a horizontal hydraulic press N, acting on the levers P P, forming a "toggle joint." The press has two rams acting in opposite directions upon two toggle joint-levers, connected by a bar Q, which moves in a vertical guide to insure a perfectly parallel action of the two points. By this means the end of the bridge is made truly parallel when the resting-blocks R R, under each girder, are put into position. To do this, three separate hydraulic cylinders, S S, are employed, as shown by figs. 3 and 4. When the toggle joint-levers P P are withdrawn, the bridge is lowered on the blocks. The hydraulic cylinders N and S are controlled by valves on the centre platform in reach of the bridgeman, who can stop the bridge at the right place by means of a dial with pointers actuated by the motion of the bridge. When the

motion is stopped, a locking-bolt T, 3 inches thick (which is pressed outwards by a spiral spring), is shot out at each end of the bridge into a corresponding slot, and so locks the bridge. These bolts are withdrawn by the wire cord U when the bridge is to be swung.

The line of the bridge being north and south, a slight lateral warping is caused by the sun acting alternately on the opposite sides of the bridge. To enable the bolts to enter their slots when the warping occurs, the feet of the lifting levers P P are bevelled on their inner faces at I I (fig. 2), and bear against corresponding bevels V V on the bed plates, by which means the ends of the bridge, when warped, are forced back into the correct line.

The accumulator being stationary, whilst the fixing gear swings with the bridge, the water-power is conveyed by a central copper pipe W (Plate 31), which passes up through the centre of the bridge, and has a swivel joint at the lower end. As the hydraulic turning-engines are also stationary, whilst the bridgeman's hand-gear rotates, the communication for working the valves is made by a central copper rod X (Plate 31), which passes down through the centre of the pressure pipe W in the axis of the bridge. The opening or closing of the bridge is accomplished in 50 seconds, the average speed of motion of the end of the bridge being 4 feet per second.

Small gas jets are provided in the central pier, and in the chambers containing the hydraulic cylinders, and are kept burning in very frosty weather. The pipes leading to the machinery at the ends of the bridge are protected by cinders encased in wooden boxes.

Another important hydraulic swing-bridge is that which crosses the river Tyne. The swinging portion of this is 280 feet long, and weighs more than 1200 tons. In this bridge, instead of the weight resting upon live rollers, a hydraulic press is applied to the centre; it has a pressure of about 900 tons upon the ram, which relieves the pressure upon the rollers to that extent. The rollers and roller path, however, are sufficiently

strong to carry the whole weight of the bridge, supposing any accident were to happen to the centre press. The central press being always open to the accumulator pressure, a permanent relief is afforded without any waste of power.

Hydraulic power has also been applied on the "Bascule" (or old lifting drawbridge) system, both single and double leaf. A bridge of this character occurs over one of the dock entrances at Liverpool. Sometimes the dip of the "Bascule" bridge is counterbalanced by the tail-end of the bridge. In some cases the bridge is hinged on the quay level, and is lifted bodily back, leaving the passage of the quay-way perfectly free and uninterrupted for passengers. There is a Bascule bridge at York in one leaf of 34 feet, which is raised by chains actuated by hydraulic rams. At Copenhagen, again, there are seven Bascule bridges, one of which, having two leaves of 62 feet each, is in the very centre of the city, and has to carry a large portion of the traffic across the harbour. It is worked by hydraulic machinery, and has been opened and closed fifty-five times in a day.

HYDRAULIC POWER AT THE. FORTH BRIDGE.

Sir B. Baker (the President of the Mechanical Science Section of the British Association in 1885) acknowledged the important part that hydraulic appliances had played in the construction of the Forth Bridge in the following words:—"More than 42,000 tons of steel plates and bars have to be bent, planed, drilled, and rivetted together before or after erection, and hydraulic appliances are used throughout. The plates are handled in the shops by numerous little hydraulic cranes of special design, without any complication of multiplying sheaves, the whole arm being raised with the load by a 4-inch direct-acting ram of 6-feet stroke. A total length of no less than 60 miles of steel plates, ranging in thickness from $1\frac{1}{4}$ inch to $\frac{3}{8}$ inch, have to be bent to radii of from 6 feet to 9 inches, which is done in heavy

cast-iron dies squeezed together by four rams of 24 inches in diameter and the same stroke. With the ordinary working-pressure of 1000 lbs. per square inch, the power of the press is thus about 1750 tons. Some 3000 pieces, shaped like the lid of a box, 15 inches by 12 inches wide, with a 3-inch deep rim all round, were required to be made of ½-inch steel plate, and this was easily effected in two heats by a couple of strokes of a 14-inch ram." He also described that, in erecting the great 1700 feet spans of that bridge, the massive girders were put together at a low level, and were hoisted as high as the top of St. Paul's Cathedral by hydraulic power. Continuous girders, nearly one-third of a mile in length, were similarly raised, together with the necessary sheds, cranes, appliances, and workmen, the whole weight on the platforms being in some instances more than 1000 tons.

In the excavation of the foundations of the Forth Bridge hydraulic appliances of a novel kind were used. The huge wrought-iron caissons (70 feet in diameter and 70 feet high) for the foundations, had to be sunk through tenacious boulder clay, which was excavated by hydraulic spades. Hydraulic rams worked in the hollow handles, which were thrust against the roof, and by turning a tap the spade was forced into the clay, with a pressure of 3 tons. These hydraulic spades were employed in an electrically lighted diving-bell 70 feet in diameter, 7 feet high, and 90 feet below the sea.

THE TOWER BRIDGE.

The bridge which Sir John Wolfe Barry has constructed across the Thames at the Tower has been described in a paper read before the Institution of Civil Engineers by Messrs. Cruttwell and Homfray in 1896.

The prominent features of the structure consist of two main towers on the river piers, and two smaller towers on the shore abutments from which the suspension-chains of the shore spans

are supported. The opening span between the two main towers consists of two leaves, or bascules, pivoted near the faces of the piers, and rotating in a vertical plane; so that when raised for the passage of vessels through the bridge, the entire waterway between the faces of the piers is unobstructed save for the high-level footways between the main towers. These footways are fixed at a level considerably higher than the masts of any vessels which use the river. The clear width of each of the shore spans between the piers and abutments is 270 feet, and that of the opening span is 200 feet. The headway of the shore spans above Trinity high-water level varies between 27 feet next the piers, 23 feet next the Middlesex abutment, and 20 feet next the Surrey abutment. The headway at the centre of the opening span is 30 feet, and the under side of the high-level footways is 141 feet above Trinity high-water level. The total length of the bridge, including the abutments, is 940 feet, and the lengths of the approaches are 1260 feet on the north side and 780 feet on the south side. The width of the bridge and approaches between the parapets is 60 feet, except across the opening span, where it is 49 feet. The steepest gradients are 1 in 60 on the north side, and 1 in 40 on the south side.

The bascules are raised and lowered by hydraulic engines acting through gearing. The operations of raising and lowering can be effected in one minute, but in practice it is about one and a half minutes.

In each main tower are two hydraulic hoists for taking passengers to and from the high-level footways while the bascules are raised. The hoists have cradles 14 feet 9 inches long, 6 feet 6 inches wide, and 11 feet high, the length of the lift being about 110 feet. The cradles are lifted and lowered by wire ropes, worked by cylinders and rams in duplicate (placed vertically in the towers close to the hoist), each of which has two lifting ropes and two counterweight ropes.

The hydraulic power for the bridge is generated in the arches of the south abutment, where two arches are occupied by two double tandem compound surface condensing engines, each of

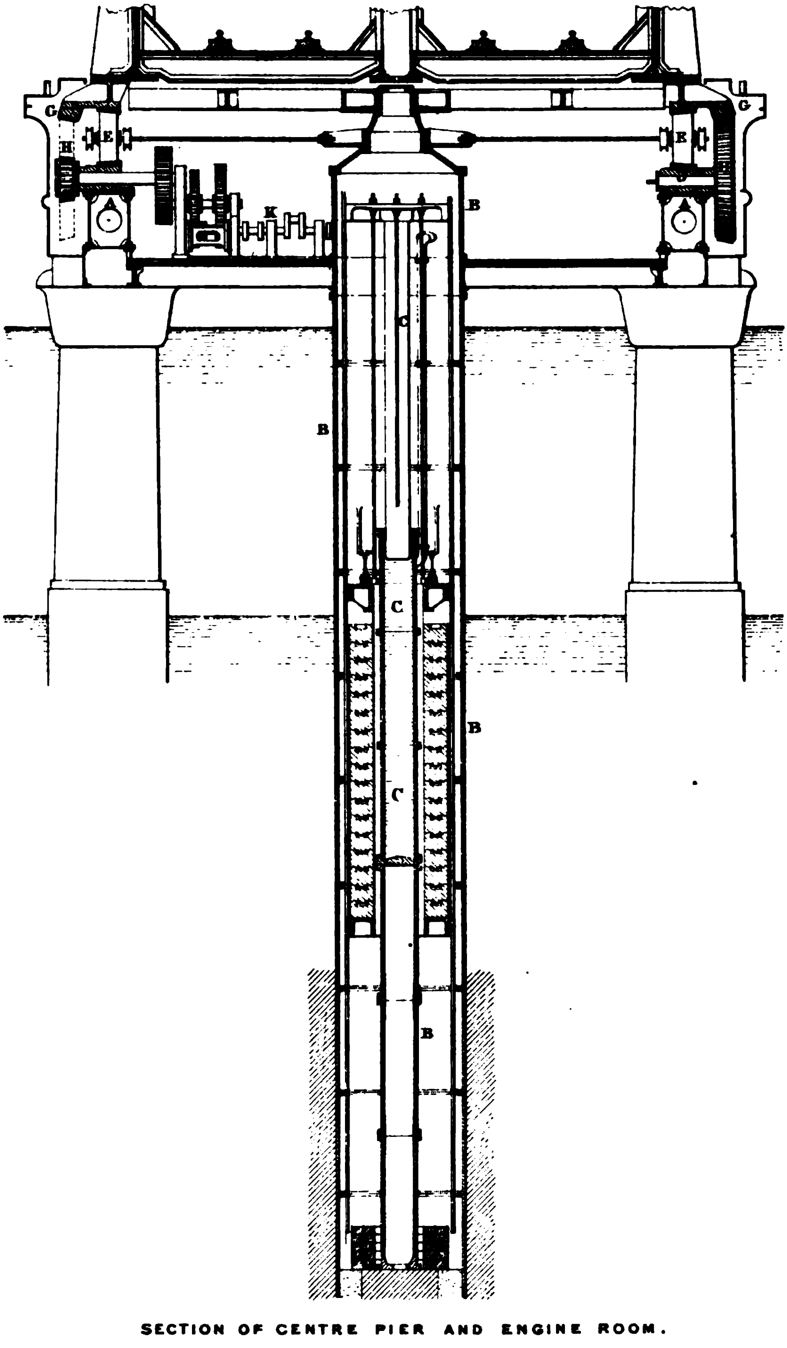
360 i.h.-p. The hydraulic pressure is 700 lbs. per square inch. At each end of each pier is an accumulator having a plunger 22 inches in diameter and a stroke of 18 feet. In addition, there are at the engine-house two accumulators having plungers 20 inches in diameter with a stroke of 35 feet.

DOCK-GATE MACHINERY.

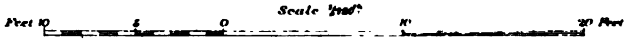
One of the first applications of hydraulic power in this direction was to the old hand-power gate machines at the docks at Newport and Swansea. Lines of shafting were carried along the dock wall, with gearing connecting the engines to each of the hand crabs. This shafting was actuated by rotating hydraulic chains, which at the same time worked capstans at the extreme end of the dock.

Hydraulic engines were next applied directly to each crab, instead of through intermediate shafting. An "Elswick gate crab," with hydraulic engine attached, is shown by Plate 33, figs. 1 and 2. In this arrangement there are two rotary hydraulic engines with two cupped drums to each, a clutch enabling either drum to be thrown into gear with the engine, whilst the other overhauls. One engine with its double crab serves for two chains, which are led along the top of the gate. The chain for opening passes over a pulley, and descends vertically by the side of the gate. After passing over another pulley, it is attached to the masonry at the place where in ordinary practice the roller-box is fixed. By this arrangement the old method of making chainways in the masonry is obviated, and each leaf of the gate is worked both ways from the same side.

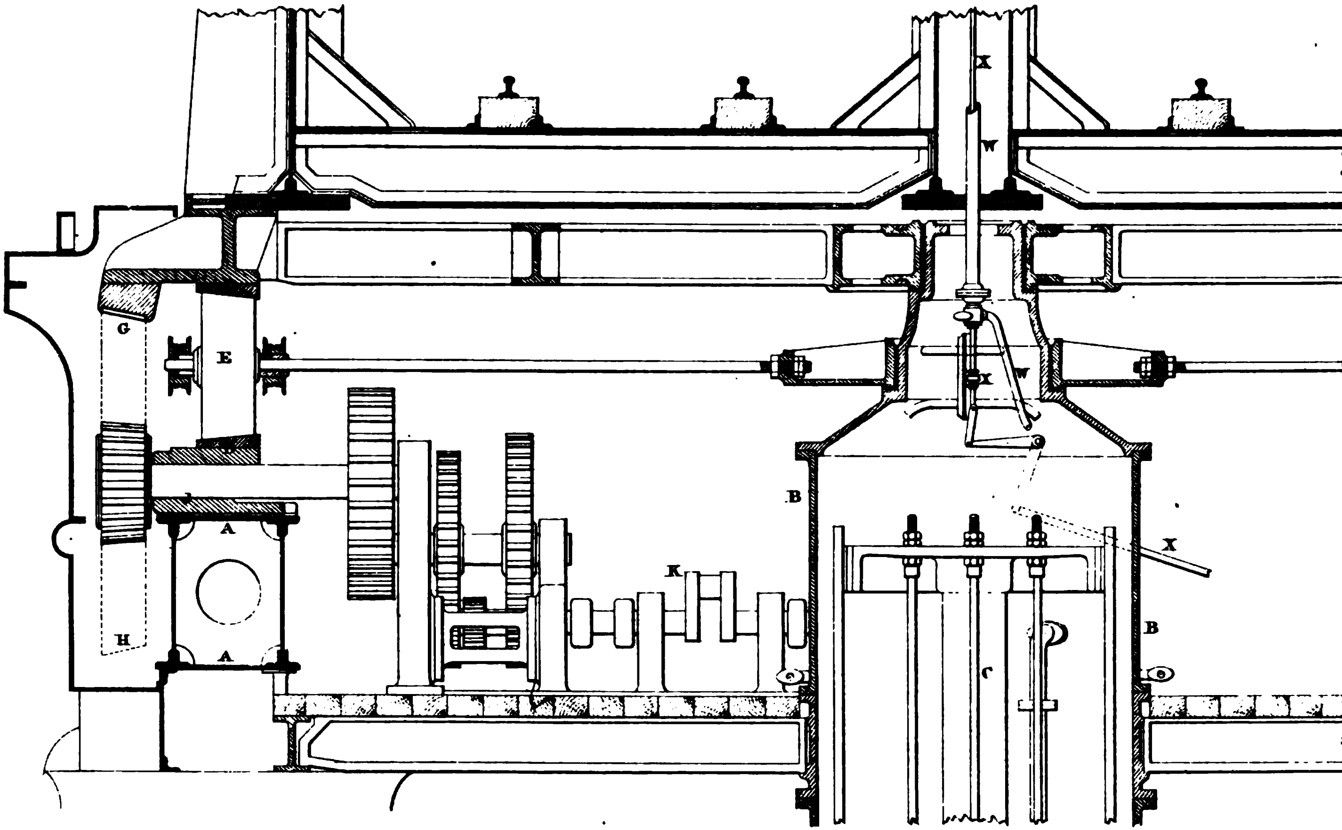
Another arrangement is that by which hydraulic power is applied to the crabs through shafting driven by hydraulic engines. By this method the opening and closing chains are led from the gates through roller-boxes in the masonry of the



SECTION OF CENTRE PIER AND ENGINE ROOM.



OUSE SWING BRIDGE.



ENLARGED SECTION OF ENGINE ROOM.

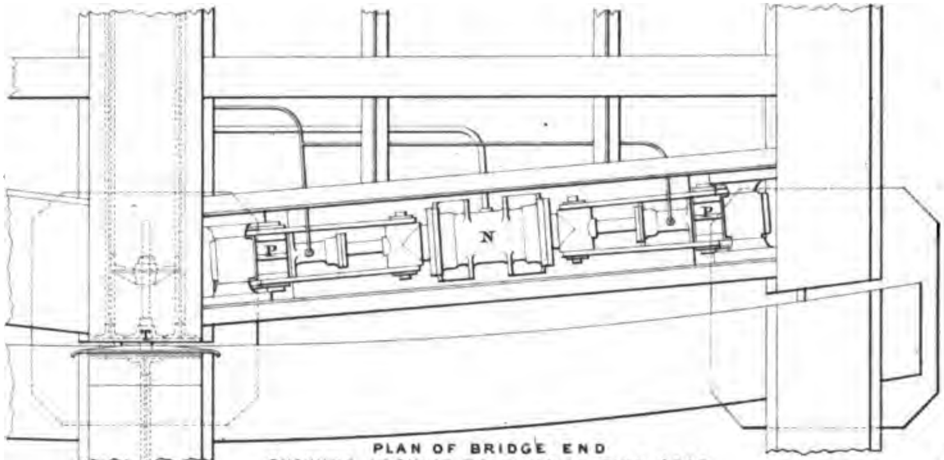
Scale 1/48th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

OUSE SWING BRIDGE,

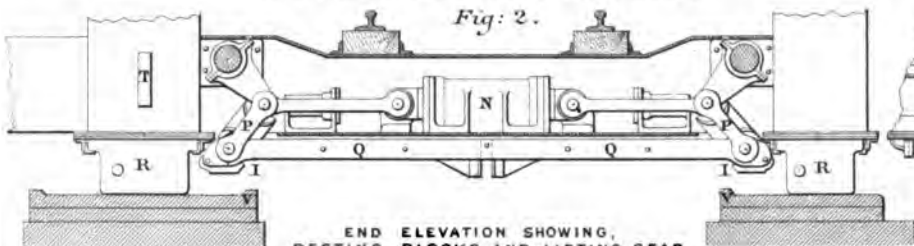
LOCKING GEAR &c AT ENDS OF BRIDGE.

Fig: 1.



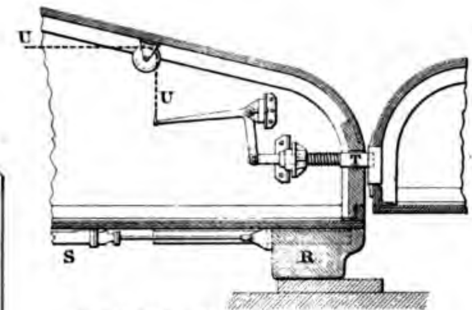
PLAN OF BRIDGE END
SHOWING LOCKING BOLT AND LIFTING GEAR

Fig: 2.



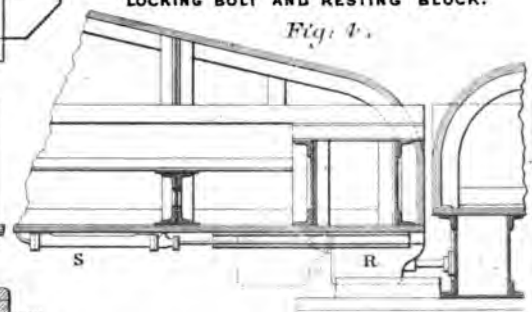
END ELEVATION SHOWING,
RESTING BLOCKS AND LIFTING GEAR.

Fig: 3.



LONGITUDINAL SECTION, SHOWING
LOCKING BOLT AND RESTING BLOCK.

Fig: 4.

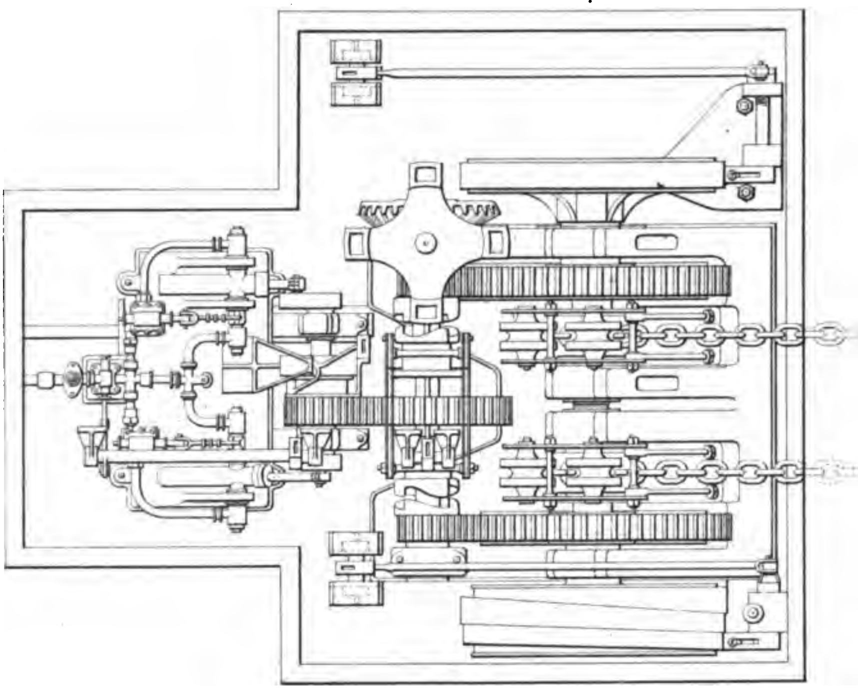


SIDE ELEVATION
SHOWING RESTING BLOCK.

Scale 1/48th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Fig: 1.



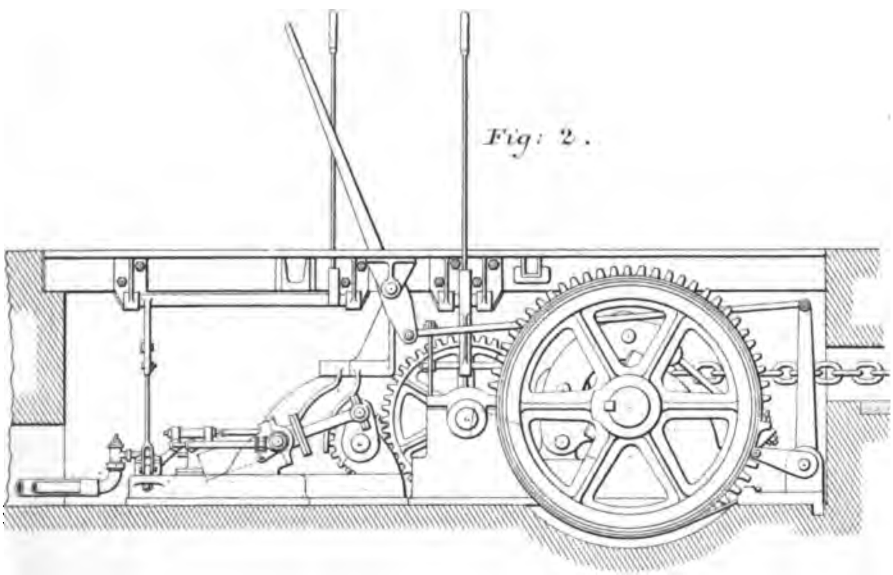


Fig: 2.

Tr. & Keil & Son, Lith.

walls, and thence up inclined chainways to separate winding-drums. These are worked by shafting from three-cylinder hydraulic rotatory engines (one on each side of the lock). The closing drums have a spiral at the end for taking up quickly the slack chain lying across the lock. When the opening drums are hauling in, the closing drums are paying out, and *vice versâ*, to effect which the drums are connected to the shafting by clutches. The drums are controlled by brakes when paying out. The shafting can be worked by hand, by means of a sunk capstan-head, in case of need. A capstan for hauling ships is also connected to shafting by a clutch and bevel spur gearing.

Another form of gate machinery is the direct-acting ram and cylinder with multiplying sheaves, which has been very generally adopted, although it does not provide for the working of the gates by hand in case of need, or if the power is not available. Plate 34 shows a "Hydraulic Machine for Opening and Closing 80-feet Lock Gates." The opening and closing chains are led from the gates through roller-boxes in the face of the walls, and up inclined chainways, to horizontal hydraulic cylinders and rams. These have multiplying sheaves, around which the chain is led, the end of the chain being attached to the cylinders. On pressure being admitted to the opening cylinder (by means of a valve in a pit adjoining), the ram is forced out, drawing up the chain, opening the gate, and pulling in the closing ram on the other side of the lock, which (by means of its valve) has been put in connection with the exhaust. For closing the gates, the operation is reversed. The ram-heads are carried by rollers on tram-plates. This arrangement is simple, and has very few wearing parts. The strain on the chain when the gate is moved is about 10 tons. The gates are opened in a minute and a half.

The illustration only shows the machinery on one side of the lock. The other is precisely similar.

The widest entrances to which hydraulic power has been applied are 100 feet at the Canada Dock, Liverpool, at the Barrow Dock, and at Birkenhead.

Sluices for removing mud at the entrance to locks can be conveniently worked by hydraulic machinery. Their movement up and down is effected by the application of direct-acting cylinders and pistons attached to the masonry to open and close the paddle against the pressure. A hand-pump is generally applied so as to be available in the event of the water-pressure being accidentally cut off. The combination is effected by a screw and gearing worked by a rotary hydraulic engine, so arranged that it can be worked by either hand or

Fig. 33.

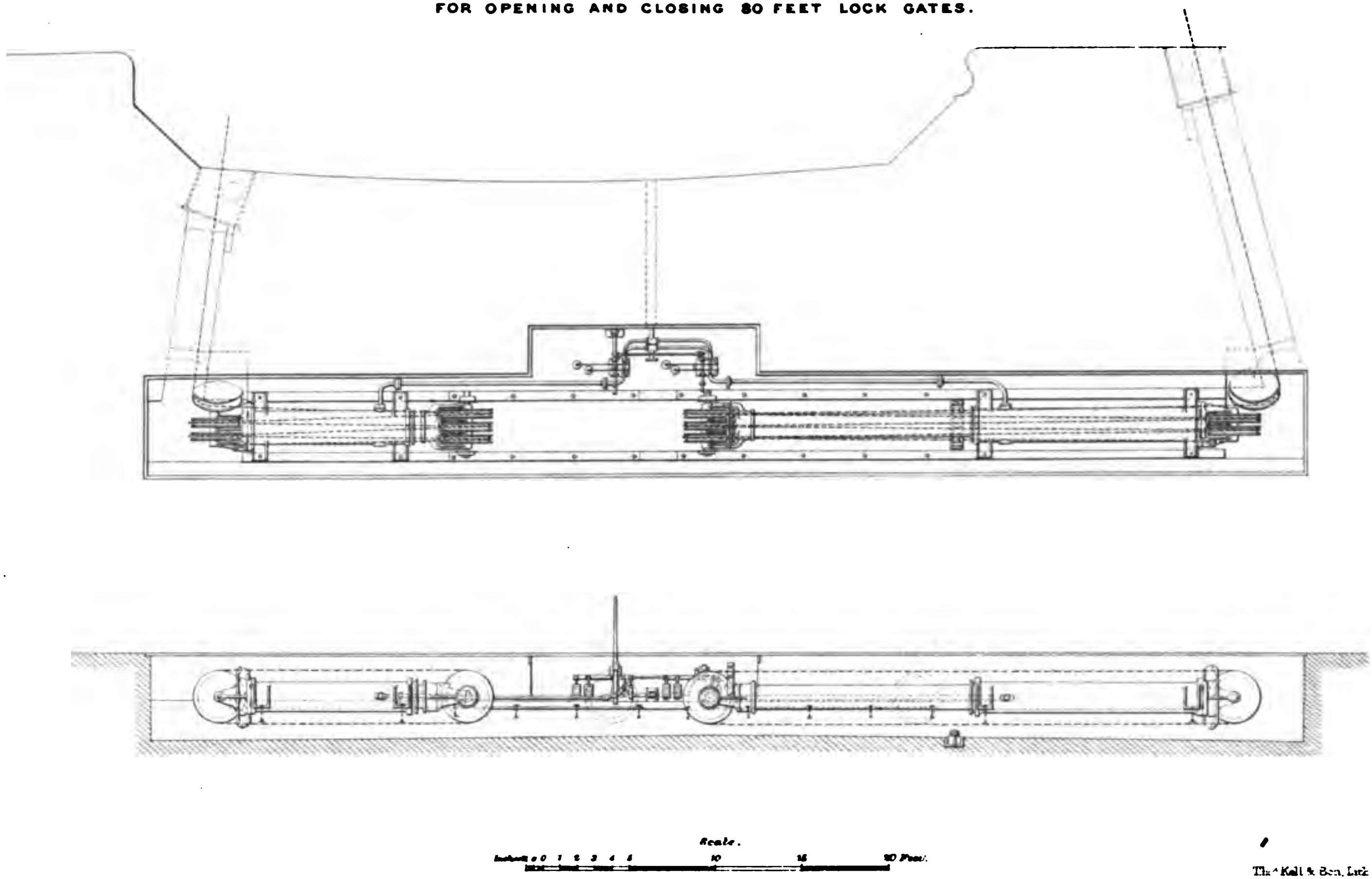
power. The sluice cylinders are usually lined, and the rods covered, with copper. Plate 35 shows an Elswick "Direct-Acting Hydraulic Sluice Machine." At the Alexandra Docks, Newport, the hydraulic sluices are attached to the gates themselves, instead of being placed on the masonry.

Lock-sluicing arrangements at dock entrances have generally failed by reason of the scouring action of the water on the mud being limited to the mouth of the sluice. Deep holes are made there, as the scouring force is not operative at any distance from the sluice. A solid apron should therefore be carried for some distance beyond the mouth of the sluice to prevent the

PLATE 34.

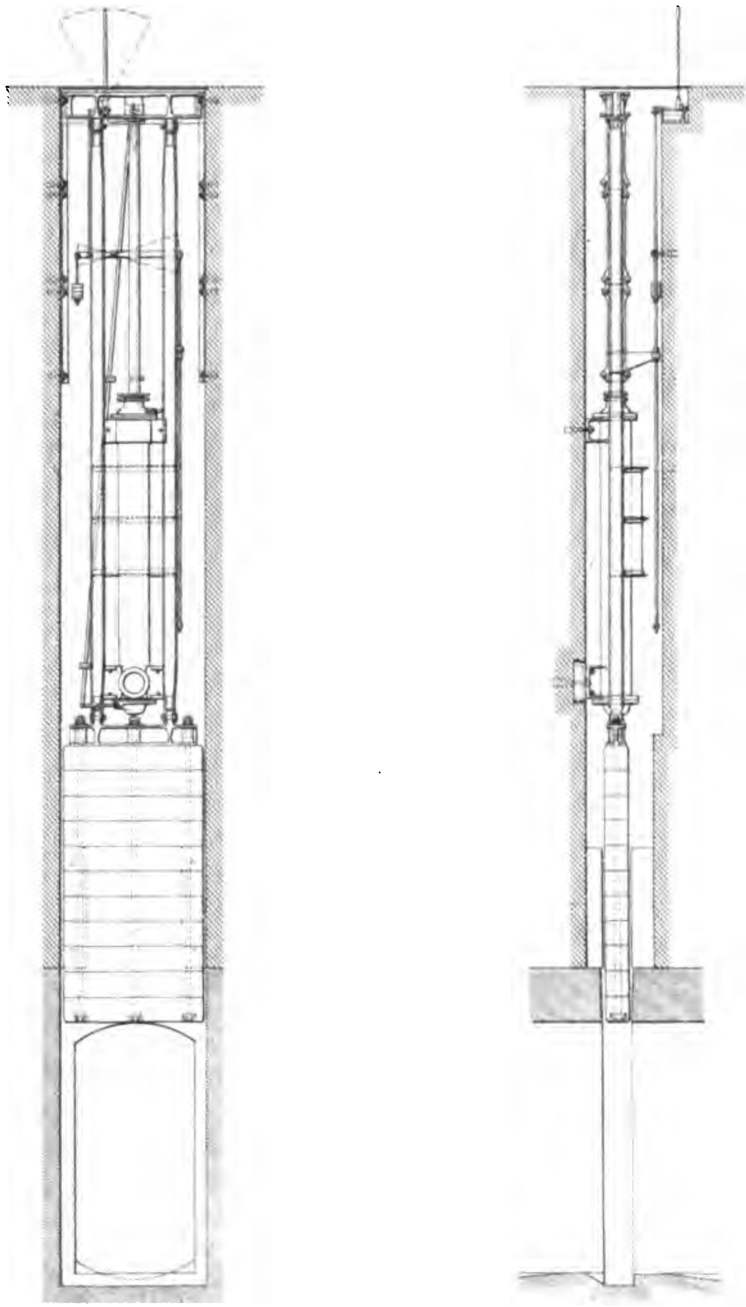
HYDRAULIC MACHINE,

FOR OPENING AND CLOSING 80 FEET LOCK GATES.



Thos Kell & Son, Lith.

DIRECT-ACTING HYDRAULIC SLUICE MACHINE.



Scale.

Inches 12 0 1 2 3 4 5 10 15 Feet

Thos Kell & Son, Lith

force of the water from disturbing the floor (as it frequently does). The current would then be directed with the best effect, and the formation of the upper eddies, which destroy the sluicing power of the water, would be avoided.

In the construction of the Barry Docks, Sir John Wolfe Barry adopted direct-acting gate machinery for opening and closing the dock gates, and the Elswick firm executed the work.

Fig. 34.

Figs. 33, 34, and 35 show the arrangement for each gate, consisting of a fixed double-acting hydraulic cylinder, the piston-rod of which is coupled direct to the gate by a connecting-rod. The cylinder is of cast iron, the piston being 19 inches in diameter, and the stroke 14 feet. The piston-rod is 7 inches in diameter; is covered with copper, and connected to a crosshead which moves between steel guides. The connecting-rod is of forged iron, connected at the inner end to the crosshead by a

forged steel gymbal, which will allow angular movement both in a vertical and horizontal direction; the outer end is fitted with another forged steel gymbal, which also allows movement in two planes. This gymbal fits into brackets attached to the gate itself, as shown. The front end of the cylinder is carried by a frame of steel plates and angles which is secured to the masonry, and takes the thrust when moving the gates. This frame also takes the inner end of the guides, the outer end being attached to another girder built into the masonry. Heavy

Fig. 35.

tie-bolts connect this girder with the cylinder frame. The rear end of the cylinder is supported by a cast-iron saddle. The working valves are of the spindle pattern; a reducing valve is fitted on the supply, so that the working pressure can be adjusted to anything between 200 lbs. and 700 lbs. per square inch. Automatic cut-off gear is provided.

SHOP TOOLS.

The employment of hydraulic pressure to workshop tools dates as far back as Bramah's time, a hydraulic planing machine having been then erected at Woolwich, in which many

of the operations of the tool were performed by water-pressure. More than forty years ago a direct-acting hydraulic slotting machine was at work for some years at Elswick. It had a stroke of about 4 feet, with a tumbling weight to reverse the action, and it was worked with an accumulator pressure of 700 lbs. per square inch. It was placed vertically upon girders supported by pillars 16 feet apart, thus enabling large pieces of machinery to be easily slotted.

The adoption of a pressure of 1500 lbs. per square inch enables the sizes of shop tools to be reduced, and their portability and convenience thereby increased; but in case a lighter description of work has to be done, the pressure can be reduced by diminishing the weight in the accumulator.

The transmission of power by a pipe (instead of by belting or shafting) for actuating shop tools, is attended with advantages. Less wear and tear arise, and the power can be conveyed round bends, or to distant points, with great facility. The pipes being underground, the cost of the supports, columns, and bearings requisite for shafting is saved.

The object which has to be attained in manipulating wrought iron under a forging, bending, or other tool is to dispose the fibres in the direction conforming to the purpose to which the iron is to be applied. Such disposition of the fibres or threads in uniformly continuous lines ensures the strength of the mass being preserved. The application of a blow results in a disturbance of this arrangement of the fibres (producing, as it were, eddies in the flow of the particles), and the power of resistance is necessarily lessened. In stamping metal, a squeeze, instead of a blow, results in the preservation of the continuity of the particles. The shapes for the dies at the various stages of the work can be considered with reference to the natural tendency of the metal to flow in the direction of the pressure which is applied to it. The element of time in these operations has been proved to be an important factor, in the changes of form which are produced in metals when being manipulated. The continuity in the fibres of the metal

is better produced by a slow blow or squeeze than with a sharp blow.

The late Mr Tweddell directed his attention to the employment of hydraulic power to rivetting and to other purposes. The result was a practical revolution in the working of many shop tools, and the following illustrations explain some of those which are made by Messrs Fielding & Platt of Gloucester, whom Mr Tweddell associated himself with at the outset of his useful investigations.

TWEDDELL'S HYDRAULIC RIVETTER.

One of Mr Tweddell's fixed hydraulic rivetters is shown by figs. 36 to 43. A side elevation is given by fig. 36, an end elevation by fig. 37. Fig. 38 is a plan and fig. 39 a longitudinal section. Fig. 40 is a back elevation, and fig. 41 is a front elevation. Fig. 42 is a sectional plan of the valve box. Fig. 43 is a longitudinal section of the ram. These illustrations are taken from the *Proceedings of the Institution of Mechanical Engineers.* The water from the accumulator is admitted to, and exhausted from, the cylinder through the small aperture A, figs. 39 and 43, by means of a simple hydraulic valve shown by fig. 42. The water entering at B tends to keep the inlet valve C shut, the spring D serving the same purpose until the accumulator pressure begins to act. On opening the valve C (by the hand-lever E) water is admitted to the cylinder and passes into it against the ram (8 inches diameter) until the rivet is closed. The exhaust valve F is kept shut by the pressure of water entering the cylinder, and at other times by the spring D, but by pulling the lever over the reverse way the exhaust valve is opened, by which the exhaust water escapes to the cistern, a small portion being allowed to flow through the pipe G (fig. 39) on to the die, to cool it. The ram H is drawn back by means of the small drawback cylinder J (fig. 43), which is

arranged within the ram itself, and is in constant communication with the accumulator through the inlet K. The wedge-shaped fastening of the disc (as shown at L in figs. 39 and 41) obviates any thickness of metal over the fixing pin ordinarily employed to keep the die in its place. This enables the rivetter

Fig. 36.

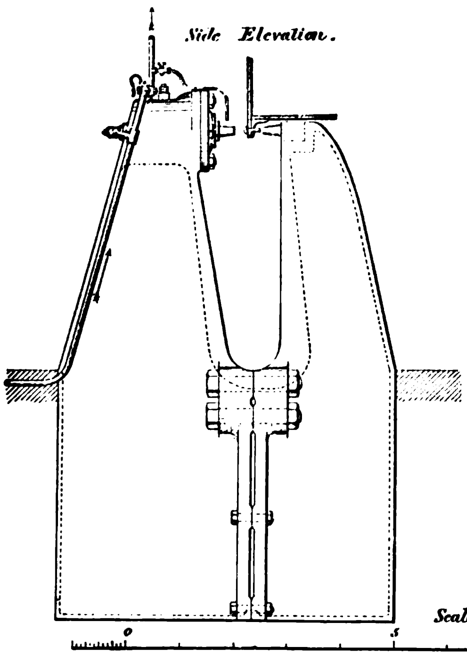
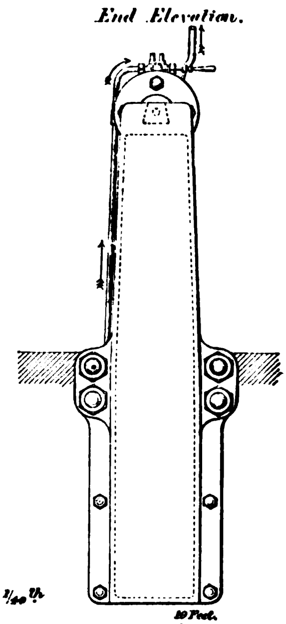


Fig. 37.



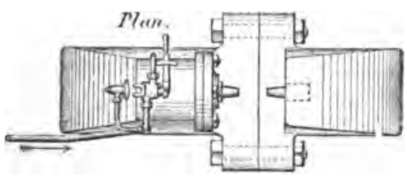


Fig. 38.

to be used for rivetting flanged and angled iron work. These designs have been altered in points of detail of late years. A piston valve with leather packing is now used instead of the mitre valve, and owing to the pressure exerted by many of these machines being from 150 to 200 tons in closing the

rivets, at the rate of four or five to the minute, the high-

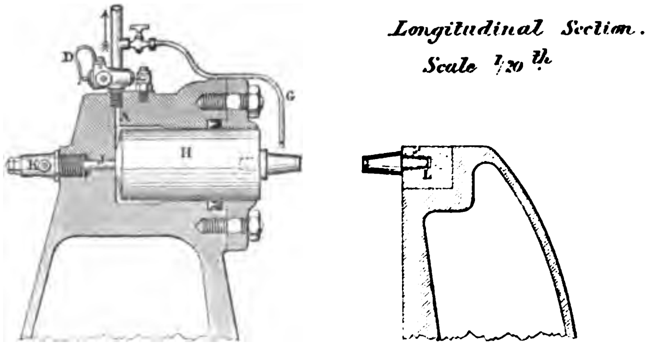


Fig. 39.

pressure water is economised by special arrangements, by which different powers are exerted. Cast steel is now largely used

Fig. 40.

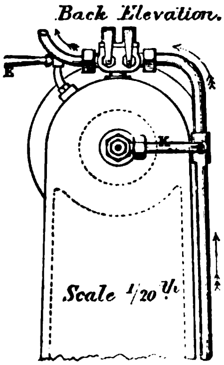


Fig. 42.

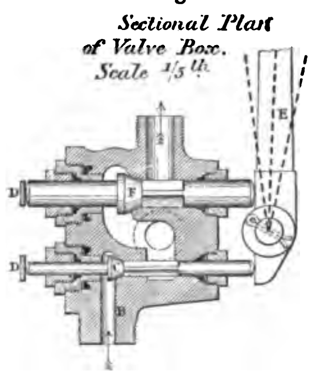
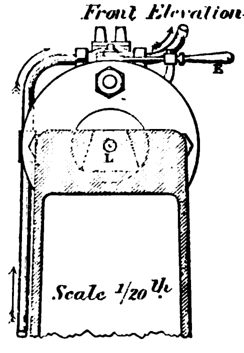


Fig. 41.



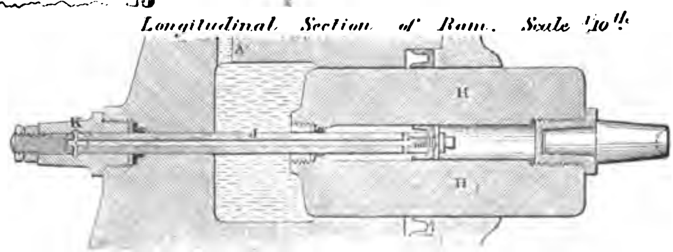


Fig. 43.

instead of cast iron for the main frames. Owing to the great thickness of the steel plates that are now employed, the rivetting

machines now have additional rams by which the plates are first brought together by a closing tool, and are so held together while the rivet is being closed by the other ram.

The success which resulted from the use of water-power when applied to the fixed rivetters, led Mr Tweddell to design a portable rivetter, which was able to be taken to the work, instead of the work having to be brought to the rivetter.

Figs. 44 and 45 show a sectional elevation and end elevation

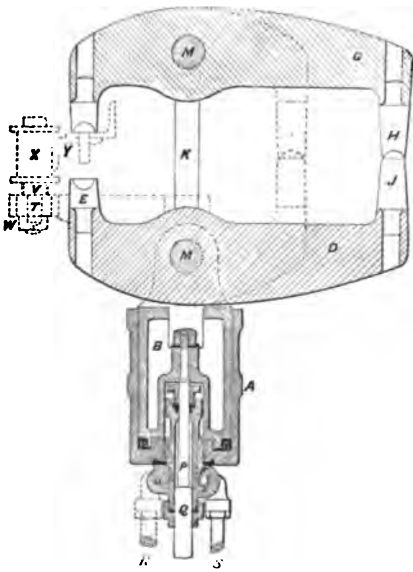


Fig. 44.

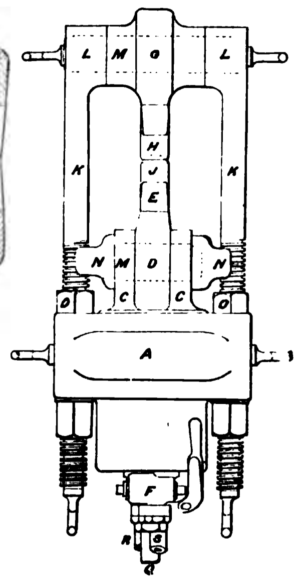


Fig. 45.

of one of the portable hydraulic rivetting or punching machines. In the cylinder A is a plunger or ram B, with two jaws C C, to which is attached a crosshead or horn D, furnished at one of its ends with the cupping die E. The plunger B being forced forward by water admitted through a valve by the gearing F, the crosshead advances until it meets the resistance of one end of the other crosshead G at a point H, which is shaped to receive J, and at the other it comes in contact with, and closes, the rivet, or punches or shears the plate, according to the purpose it is used for. At the same time the outside crosshead (or one

farthest from the cylinder) is held up against the crosshead D by two tension rods K K attached to the crosshead G at L L, and to lugs cast on the cylinder, the rods receiving the thrust. The horns or crossheads are supported by the through pins M M, whilst the horn which is attached to the plunger B is steadied by the guide N. The nuts O O regulate the distance from the face of the cylinder A to the centre line of the crosshead G. The ram B is always subject to a drawback action owing to the self-acting cylinder P having the accumulator pressure constantly exerted upon the shoulder Q. This power comes into action as soon as the water is exhausted through the valve F. The water-pressure is admitted to the cylinder P by the inlet pipe R, and is exhausted by the pipe S, both being worked by a handle.

The dotted lines show the arrangement for keeping the machine up to its work. A frame T is fixed to the outer horn D, and in this is a pin V attached to the frame by a nut W, and having on it a roller X, which has a free rotary motion. The roller is covered with some flexible material, and serves to keep the machine in its right place, and up to the work Y.

A form of portable hydraulic rivetter is made which can be fixed to a bracket temporarily at any part of a yard where rivetting has to be done, that admits of the temporary setting up of a portable machine. Where hydraulic power is applied to movable machines, the high-pressure water is conveyed to the machine by lengths of copper pipe twisted spirally, and having universal joints, which arrangement forms a good elastic connection capable of being turned in any direction. The continuity of the supply to meet the varying positions of the machines is ensured by a ball-and-socket joint, and by a double right-angled joint, as shown by fig. 46.

Where plate-work has to be put together abroad, the conditions of labour render it difficult to ensure thoroughness of work in rivetting, and it is often worth while to set up a small hydraulic power installation to rivet by these machines, so that the certainty of good work, with the minimum of hand labour,

is ensured. Where the transport of the heavy weights for ordinary accumulators is a difficulty, a high pressure on water can be obtained by applying low-pressure water from a cistern to the large (or low-pressure) piston of an "intensifying accumulator" already described. By means of a portable engine, water is pumped into the small end of this accumulator, from which it is conveyed by a high-pressure pipe to the machines. A pressure of 20 lbs. per square inch can be obtained on the large end of the piston of the intensifying accumulator with a head of water in a cistern of about 40 feet; and as this water is not consumed, but remains permanently acting on the larger

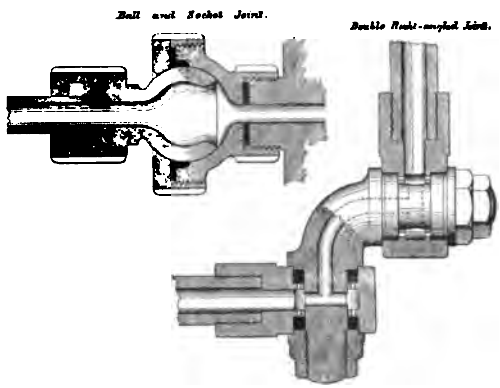


Fig. 46.

area, no waste takes place. A small tank holding 30 gallons will keep a 6-inch portable rivetter in full work, at a pressure of 1500 lbs. per square inch.

Hydraulic rivetters are applied with great advantage in shipbuilding, and the results lead to the opinion that the strength of the ships which are thus rivetted is increased. The best authorities are agreed that on machine rivetting the strength of the steamships of the future, with their increasing engine-power, and with the corresponding strains and vibrations, largely depends. By means of hydraulic rivetters, not only is the quality of the work improved, but a labour-saving appliance is employed in a class of work requiring but little skill.

At the London and North-Western Railway Locomotive Works at Crewe, Mr Webb employs hydraulic rivetting machines to rivet locomotive boilers and engine side frames. He considers that work done by hydraulic machines is superior to, and cheaper than, work done by hand or steam. He examined some plate work that had been rivetted under a pressure of 47 tons, and it was found that the plates had not suffered at all by the action of the hydraulic rivetter. The "drifting" of the holes, which is necessary in hand rivetting, he considered to be more productive of injury to the plates than any combined squeeze and blow of a hydraulic rivetter. The closeness of the work that hydraulic rivetters turn out has been proved by the fact that some portable boilers made by them have been found to be steam-tight without caulking. The plates in these cases were $\frac{3}{8}$ of an inch thick, and the rivets $\frac{5}{8}$ of an inch. The avoidance of caulking is important, as it prevents the interference with the close contact of the plates, which occurs sometimes in caulking.

The application to a rivet of a combined blow and squeeze (like that obtained from a hydraulic rivetter) prevents the formation of a shoulder on the rivet between the plates, such as is produced occasionally with machine rivetting, when a sharp powerful blow is applied. It is desirable to prevent shoulders, as they involve drilling out the rivet, and the caulking of the joint.

The action of hydraulic pressure in rivetting operations has been well shown by indicator diagrams taken from the pressure cylinders of the Tweddell rivetting machines at the Toulon Dockyard. Professor Unwin pointed out (in a lecture on Water Motors at the Institution of Civil Engineers) some interesting features which were exhibited by these diagrams, as they differ altogether from those taken from an ordinary steam-engine. A steam-engine is actuated by a fluid of comparatively little weight. Water, however, being 500 times as heavy as steam, involves the consideration that its weight acts with, and increases that of, the piston. For instance, in the

case of a rivetter worked from a differential accumulator through a 1-inch pipe, the velocity with which the water is forced by the accumulator through the pipe to the rivetter is increased or diminished according to the speed of the rivetter ram, by which the mass of water in the accumulator cylinder and pipe acts both to increase or diminish the effect produced by the ram. Assuming, as is the case in practice, that the motion of the loaded ram of the accumulator is six times as fast as the rivetter ram, the inertia of the accumulator load is 36 times as great as it would be if it moved at the same speed as the rivetter ram. Further, the force due to the inertia of the water passing into the rivetting cylinder is more than

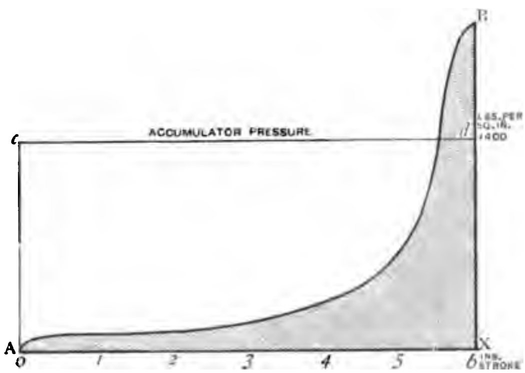


Fig. 47.

6000 times as great as would be the case if the water and rivetting ram travelled at the same speed, owing to the fact that the velocity of the water is 81 times as great as that of the ram. This results in the weight of the ram, which closes the rivet at each stroke, exerting a force of 300 tons.

Professor Unwin has shown by indicator diagrams the action that takes place in a rivetter cylinder. Fig. 47 is a diagram from a rivetter driven by a differential accumulator through 30 feet of 1-inch pipe. It will be seen that whilst the pressure is least at the beginning of the stroke, it jumps up at the end of the stroke above the accumulator pressure of 1400 lbs. per square inch, showing the action of the machine to be favourable

to the work to be performed, by slowly closing the rivet at first, and then by bringing the maximum pressure, in the form of a squeeze, at the last. The rectangle A *c d* X would be the diagram without friction and inertia, but the actual pressure is much less, being only the shaded part of the figure. Fig. 48 gives an analysis of the friction.

The friction of the cup-leather of the rivetter is shown by the small shaded rectangle A *a b* X, and the friction of the packing of the accumulator is shown by the small shaded

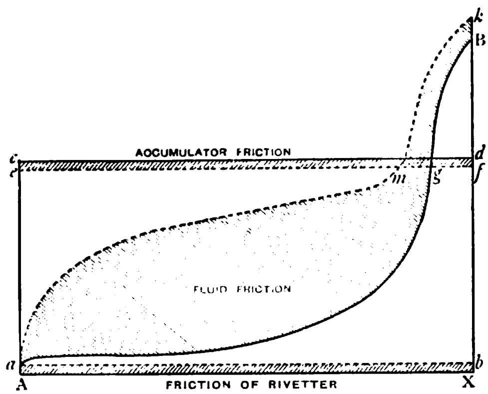
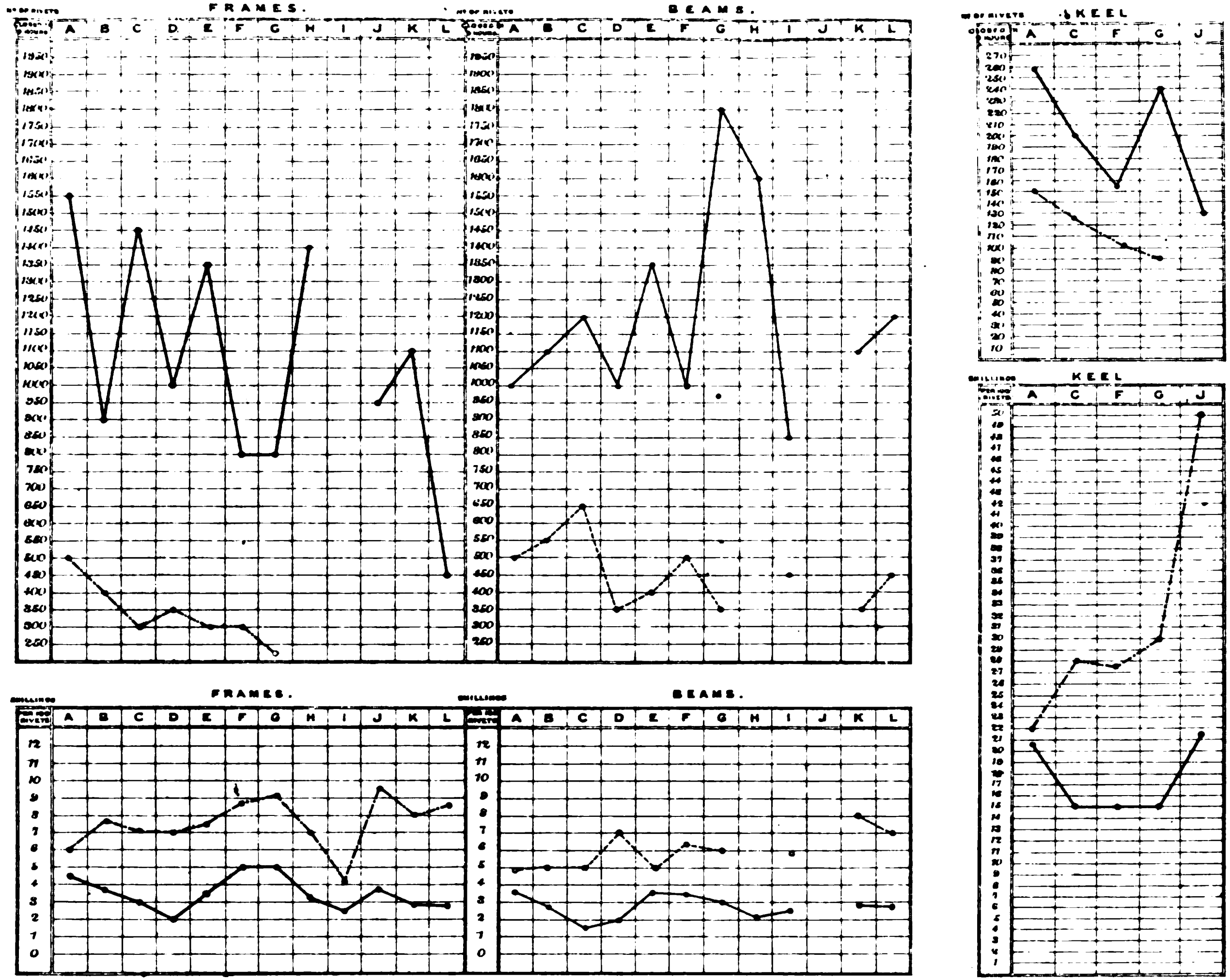


Fig. 48.

rectangle *e c d f*. The friction of the water in the 1-inch pipe is shown by the large shaded surface *a m k* B *g*, and this friction maintains the safe working of the machine at about a foot per second. The two blank spaces *a e m* and *m k f* represent the stored work in the first half of the stroke, and the excess of work at the end of the stroke, respectively, which is also shown by fig. 49.

Rapidity and economy result from the use of hydraulic power in rivetting, as compared with hand labour. Even in heavy work, hydraulic rivetters have put in 1000 1⅛-inch rivets in 1-inch plates in an ordinary day's work of 10 hours. In portable boiler-work the average rate of working is 7 rivets per minute, and it has been recorded of one machine that it put in an average of 5000 rivets a day for several weeks.

RELATIVE RATES OF MACHINE & HAND RIVETTING.



RELATIVE COST OF MACHINE & HAND RIVETTING.

Thos Kell & Son Lith

With adequate accumulator power 15 rivets per minute can be put in.

Plate 36 gives the result of a large number of observations as to the comparative speed and cost of work done by portable rivetting machines and hand work. In all cases the hand work is shown in dotted lines and that of the machines in full lines.

The quality, economy, and superiority of the work performed by hydraulic rivetters indicate that it will be universally adopted in the future where water-power is available, or where the permanency of the demand for the power justifies the installation of it. Many interesting experiments

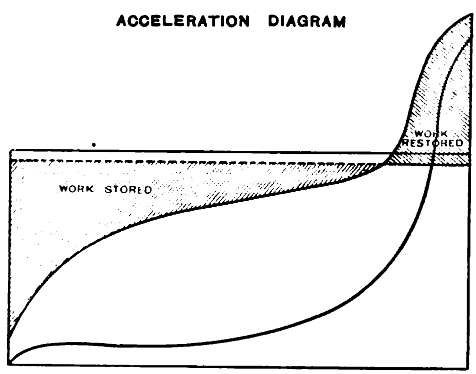


Fig. 49.

have been made by Professor Kennedy on "Rivetted Joints," the results of which have been described in papers to the Institution of Mechanical Engineers. In considering the strength of a joint it is important to notice not only the strain at which fracture takes place, but also that at which the joint begins to give way by slipping. Judged by this standard the machine work was shown to be much stronger than the hand work. In hand rivetting $\frac{3}{8}$-inch plates, it was found that slipping began at 27 per cent. of the breaking strain, whereas in the machine joints the slipping did not commence till the strain had reached 59 per cent. of the breaking strain. In the hand-rivetted $\frac{3}{4}$-inch plates, slipping

began at 16 per cent. of the breaking strain, and in the machine-rivetted at 28 per cent. This appears to show conclusively that, regarded from a practical point of view, machine-rivetting possesses very decided superiority over hand work. In these experiments Tweddell's machines were used, and the pressure upon the rivet-heads was 35 tons per square inch. The loads per rivet at which slipping began were found to be for $\frac{3}{4}$-inch rivets single rivetted by hand $2\frac{1}{2}$ tons, for $\frac{3}{4}$-inch rivets double rivetted by hand 3 to $3\frac{1}{2}$ tons, for $\frac{3}{4}$-inch rivets double rivetted by machine 7 tons. The corresponding loads for 1-inch rivets were 3·2, 4·3, and 8 to 10 tons respectively. It is thought that the load at which visible slip commences is probably proportional to the load at which leakage would occur in a boiler.

HYDRAULIC STATIONARY RIVETTER.

Fig. 50 shows one of the latest stationary rivetting machines, specially adapted for dealing with marine boilers. This machine is fitted with the plate-closer system, consisting of an arrangement for pressing the plates tightly together whilst closing the rivet. This system was first devised by Mr John Fielding to meet the requirements of the rapidly-increasing pressures which were demanded in connection with triple and quadruple expansion marine engines. These machines can also be used without plate-closing, as double or (in some cases) treble power machines, and can thus deal with a great variety of work besides the heavy boiler shells. They are made, if required, with both the main standard and hob in steel, cast in one piece up to a certain weight, and beyond this bolted together like the illustration.

Fig. 51 shows one of Tweddell's hydraulic portable rivetting machines of the direct-acting type, the power cylinder being formed on the end of one of the arms. It is shown fitted with a universal hanger, enabling the machine to be turned and worked

in any position without breaking the joints. These machines are also fitted with simpler forms of hanger from an eye bolt (enabling the machine to be used in a horizontal or vertical position) to the compound hanger shown, and they are made from 3-inch gap up to 7 feet 6 inches, and even larger.

Fig 52 shows a type of portable rivetter, being the Fielding

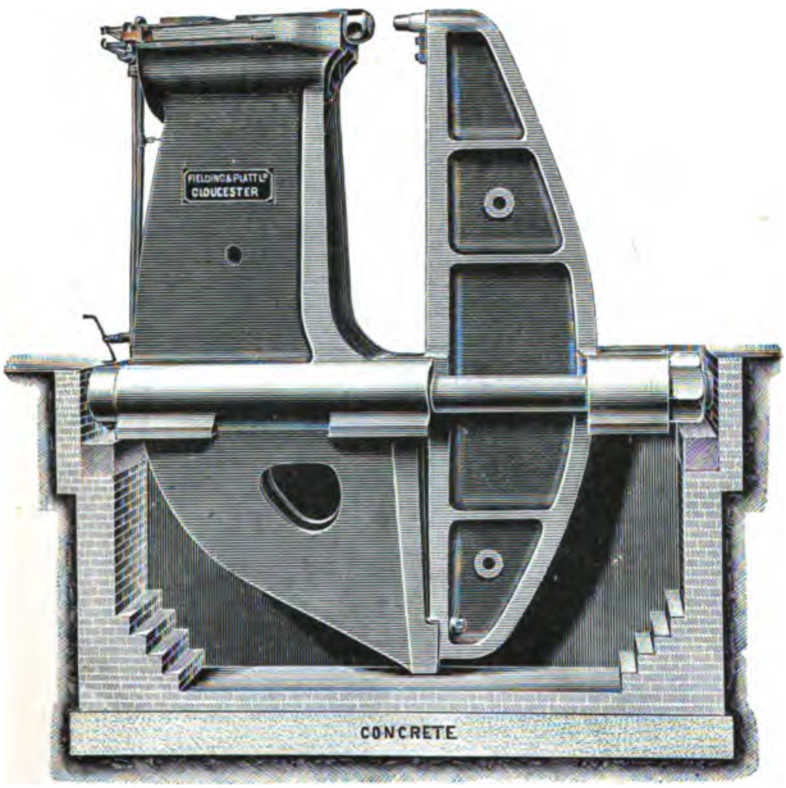


Fig. 50.

"hinged" type, which is preferable where it is important to have both the rivetting dies clear of the hydraulic cylinder, so that they may get into corner work, and rivet angle irons on to flat plates, etc. In it, both the rivetting dies are clear, and the levers carrying them oscillate on a strong steel centre-pin or gudgeon. The hydraulic cylinder and ram are

placed at the other end of these levers, and by making the centre line of this cylinder follow the radial path of the arms, of which the cylinder forms the outer end, connecting rods between the two levers are avoided. The result of this arrangement is that the machine is in practice as rigid and stiff as if it were in one casting.

The form of hanger of this machine admits of the arms being

Fig. 51.

placed either vertically or horizontally, as shown, and, of course, in any intermediate position in the same plane. If desired, suspension eye bolts only are furnished, suspending the machine either vertically or horizontally, but not in any intermediate position. By means of the compound hanger, the rivetter can be moved into any position, without interfering with the passage of pressure water to the cylinder.

Fig. 53 shows one of Tweddell's hydraulic vertical boiler shell plate bending machines, which is coming into use instead of bending rolls. The latest machines are capable of dealing with plates up to 2 inches thick. The practical results which are claimed for this machine are that the plate is bent to a true curve practically to the end, and much more completely than is possible with roller machines; that narrow curved plates or

Fig. 52.

joint strips can be bent as well as complete shell plates; that it is impossible to over-feed, and thereby break, the machine. Plates can be bent much quicker than by rolls and with less labour. Less floor space is required, a machine capable of bending plates of cold steel 1⅝ inches thick, 13 feet wide, only taking up a space of 15 feet by 5½ feet. It can be placed in any position irrespective of shafting, and requires no separate steam

engine. It is less costly than bending rolls of equivalent capacity. The mode of working is extremely simple. The plate being placed edge up on small rollers on a level cast-iron floor, is hauled through the machine in short steps of about 3 inches length, by automatic feed gear, at every stroke of the bending die. No additional manipulation by the attendant is necessitated by this new arrangement; all that he has to do is to work one valve lever, and the machine takes in the straight plate and turns

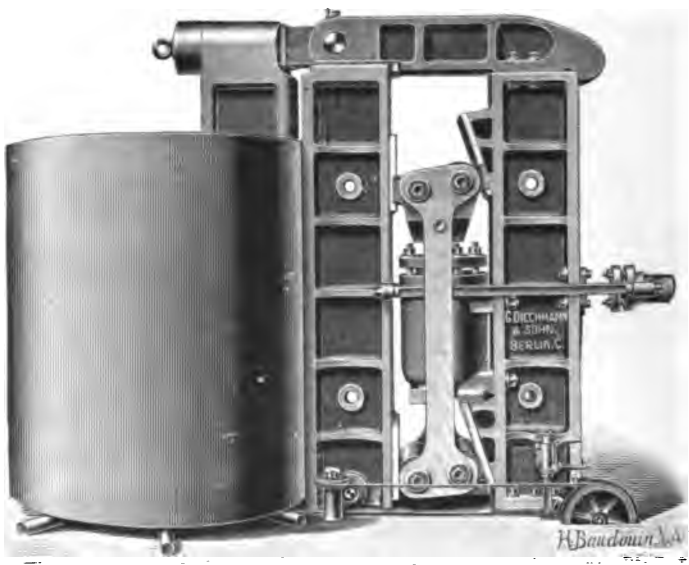


Fig. 53.

it out bent to the required curve at one passing through the dies. Nearly all manual labour is therefore dispensed with, a boy to work the valve, and a man to test the curvature as the plate issues from the dies, being all that is required. The speed of working is such that a large plate 1⅝ inches thick, 13 feet wide, can be bent with final curve at from 2 to 3 feet per minute. These machines are usually made to suit the standard pressure of 1500 lbs. per square inch, but can be made to work at any other pressure if desired.

Fig. 54 shows a Tweddell hydraulic flanger which is designed to do the work step by step, and following generally, but more perfectly, the present hand process, thus making unnecessary the expensive dies and moulds that are required for flanging at one stroke of a press. They are constructed with three hydraulic cylinders, two vertical and one horizontal. The outer vertical

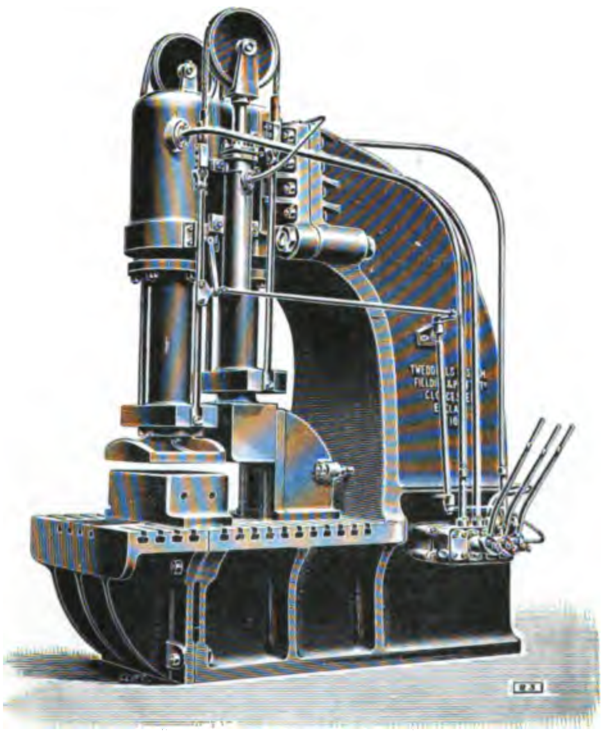


Fig. 54.

ram grips the plate on the segmental block, representing a portion of the circumferential flange, while the inner ram in its descent turns down the plate. After about 8 feet to 9 feet of the flanging is thus done, the inner ram is raised out of the way and the ram of the horizontal cylinder advances and squares the flange up. For flanging boiler fronts the dies and guides are removed, and the dome ends and furnace mouths are

flanged by dies of the usual construction. In this case the two vertical rams of the same machine are coupled together by the top block, thus utilising their combined power.

Fig. 55 shows one of Tweddell's hydraulic flanging presses for flanging boiler plates, etc., at one operation. It has a main

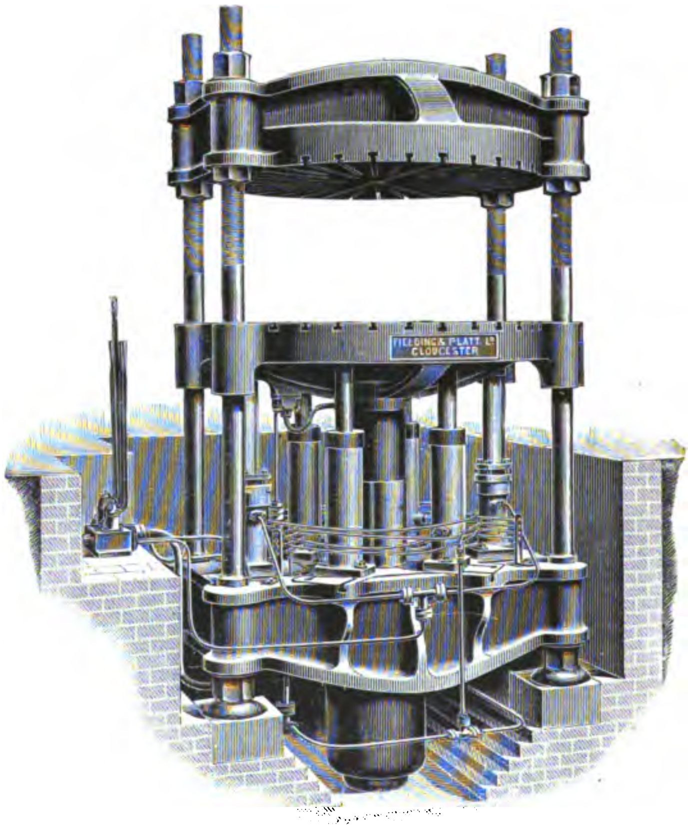


Fig. 55.

ram working from below with four vice, or holding, rams for holding the plate up against the surface of the upper die. A central vice ram is sometimes fitted inside the main ram for holding smaller plates which cannot be reached by the outside supplementary rams. A water-saving arrangement is shown,

consisting of two small rams for moving the press table until it comes in contact with the work, when pressure is automatically admitted to the operating cylinders. Whilst the press table is being raised by the small rams, the main cylinder is kept filled by water from an overhead tank, or other low-pressure service.

Hydraulic power has been applied to weld pipes made of wrought iron or steel, and the processes employed result in the joint being practically of the same strength as the solid plates. Messrs Thos. Piggott & Co. of Birmingham have devoted much attention to this, and the following data are based on their experience. Rivetted pipes of all diameters are generally made in 25-feet lengths, this being found most suitable from long experience. Welded pipes, from 30 to 60 inches diameter, are made in 24-feet lengths, being built up of three cylinders, each 8 feet long, and joined together with welded external circumferential butt straps, shrunk on and rivetted; these pipes are of especial advantage where external earth pressure has to be resisted, as the butt straps add additional strength. Welded pipes under 30 inches diameter are generally made in lengths varying from 15 to 18 feet from a single plate, although in cases where greater lengths are required they can be joined together by means of butt straps, as before mentioned, or circumferentially welded, so that as far as the length is concerned there is not much advantage in using either the rivetted or welded type of pipe. These pipes are made in thicknesses from $\frac{1}{8}$th of an inch to 1 inch, according to the pressures and purposes for which they are intended.

For lapwelded pipes steel, and not iron, plates are more suitable for manufacture in every way, possessing all the advantages of the latter without its defects. It can be more readily worked up, is much stronger and more reliable. If wrought-iron plates are used, they have to be rolled with the grain running circumferentially, to prevent cracking; whereas in steel this precaution is unnecessary, as the tensile strength, elongation, and contraction of area are almost identical, taken

either lengthwise or crosswise of the plate. All plates should be uniform, of a fine close texture, free from blisters, laminations, and other marks or imperfections due to defective rolling, and the surfaces smooth and even.

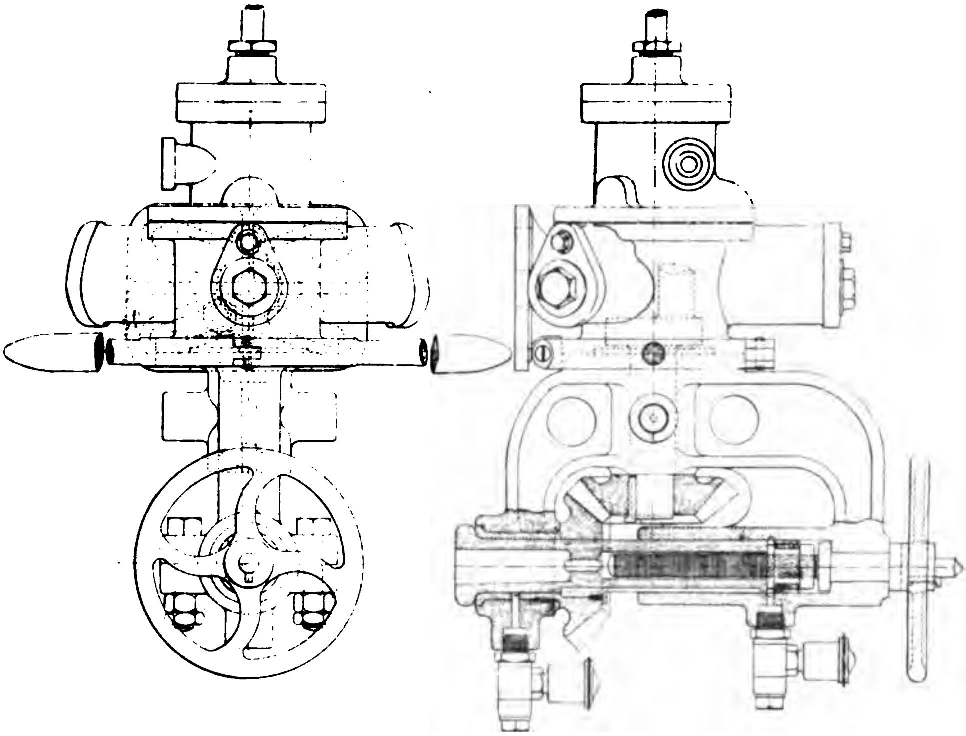
The most suitable quality of steel is Siemens Martin, made by the acid open-hearth process, having lengthwise or crosswise a tensile strength of 24–27 tons to the square inch, with an elongation of 20 per cent. in 10 inches, and a minimum reduction of area of 50 per cent. Strips $1\frac{1}{2}$ inches wide heated uniformly to a low cherry red and cooled in water of 82° F. should stand bending double in a press to a curve of which the inner radius is $1\frac{1}{2}$ times the thickness of the plate, the area of cross section of the test pieces being not less than $\frac{1}{2}$ inch.

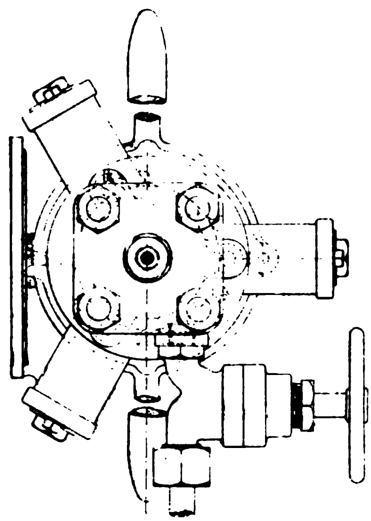
The longitudinal edges of the plates to be welded together are accurately planed to form bevelled or scarfing edges, and are of such a width as to finish to the required diameter of the pipe. The plate is then rolled up so as to give a uniform overlap equal to the thickness of the plate throughout its whole length. The curved plate is then placed on a trolley and the lap heated by water gas under a tuyere furnace to a welding or bright yellow heat. The curved plate is then run under a steam hammer and welded up, being smartly handled, so as to get the best effect out of each heat. The heat is applied rapidly and regularly, so as to prevent injury to the plates from unequal heating. After welding, the pipes are re-heated in a furnace to a good red heat, and then re-rolled, to ensure their being perfectly cylindrical. The pipes are then allowed to cool in a dry place where sudden chills will not affect them, thus allowing them to be perfectly annealed. The pipes are then faced in a special machine at one operation, thus being left perfectly square with the axis.

HYDRAULIC DRILL.

Plate 37 shows a Marc Berrier-Fontaine direct-acting hydraulic drilling apparatus. It consists of a three-cylinder

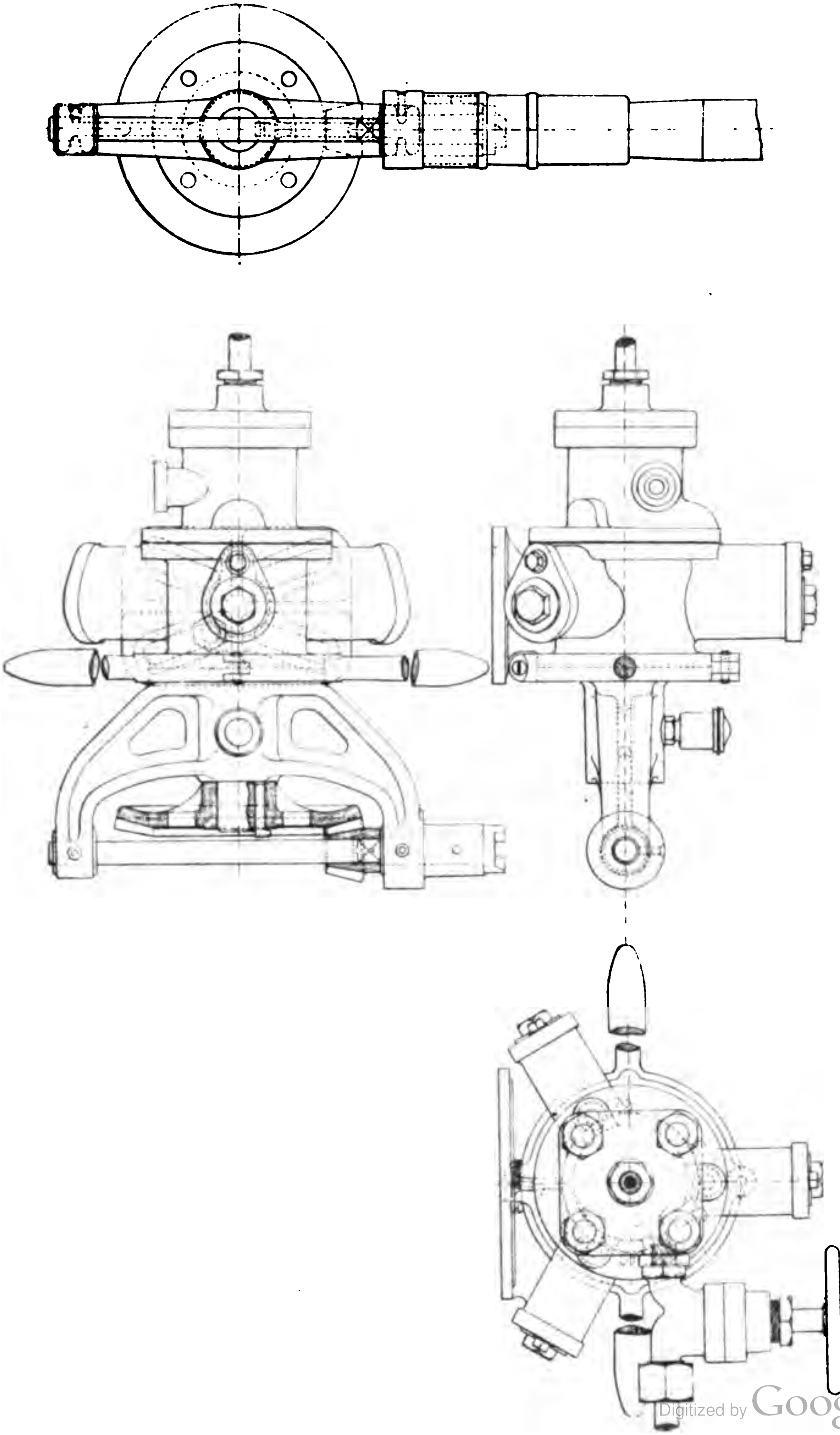
HYDRAULIC DRILL. PLATE 37.





West, Newman Photo.

HYDRAULIC ENGINE,
WITH STOWE SHAFT ATTACHMENT.



hydraulic engine connected directly to the drill press. The apparatus is made in various sizes and forms. The one illustrated has cylinders $1\frac{3}{16}$ inches diameter with a stroke of $1\frac{3}{16}$ inches, and is designed for working pressures up to 1500 lbs. per square inch, being capable of drilling holes of $1\frac{1}{4}$ inches diameter in iron or steel, the drill spindle having a feed of 4 inches. The apparatus is provided with clip handles, so that it may be readily fixed in any required position. The pressure water for driving the engine, and the exhaust water from it, are conveyed through flexible tubing, a stop valve being fixed on the valve chest to regulate the running of the engine. This machine is well adapted for structural work, such as for boilers, girders, etc., and also for use in shipyards for drilling holes in place during construction. The machine that is illustrated weighs about 85 lbs. A larger size, which is capable of drilling holes up to 2 inches diameter, weighs about 110 lbs.

Plate 38 shows another form of the apparatus, the motor and drill press being separated, the power being conveyed through a flexible shaft. In this case the engine is bolted to a driving attachment, to which one end of the flexible shaft is connected, the other end being connected to the drill press. This form of the apparatus allows of the engine remaining in one place whilst any number of holes may be drilled within the range of the flexible shaft, the drill press only being moved from hole to hole. The apparatus, like the direct drill, is provided with handles for carrying about.

MANHOLE CUTTER.

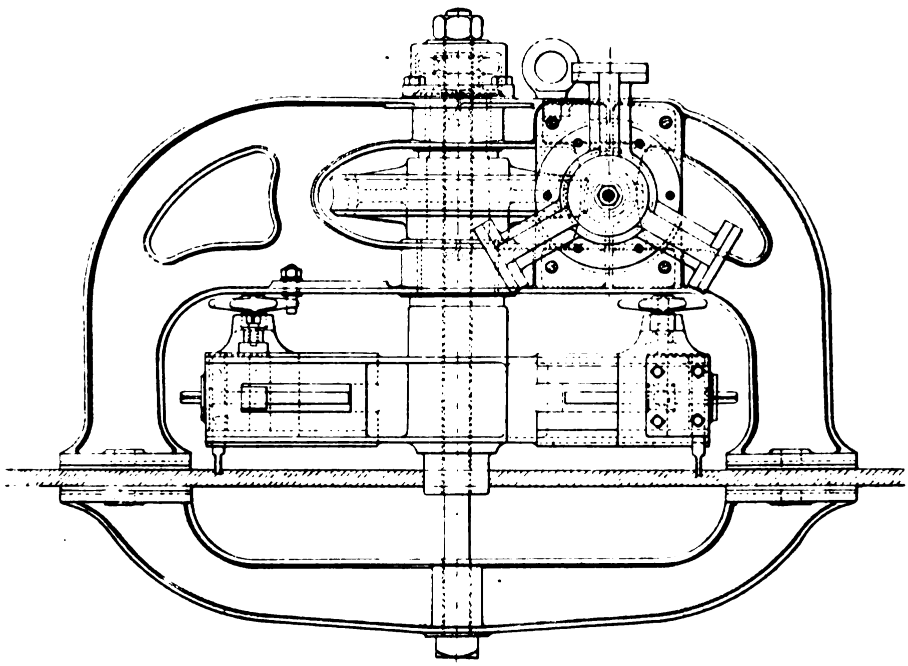
Plate 39 shows a Marc Berrier-Fontaine hydraulic manhole cutter for cutting circular or oval manholes of any diameter up to 30 inches, in iron or steel. The double radial arm which carries the cutters is driven by a three-cylinder engine through worm gearing. The engine has cylinders $1\frac{3}{4}$ inches diameter, with a stroke of $2\frac{1}{2}$ inches. The feed is given to the cutters

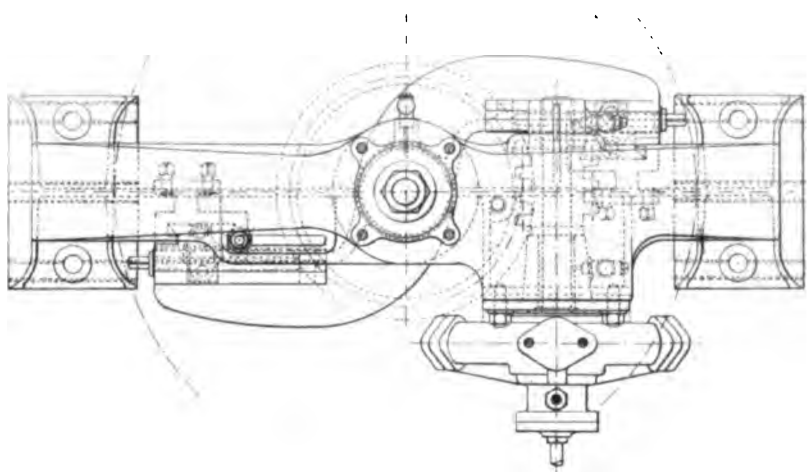
automatically, the star wheels on the feed screw engaging with a stud on the frame at each revolution. The machine is held to its work by means of a tension bolt (passing both through the frame and the plate to be cut) to a light steel bridge bracket on the other side of the plate. The only preparation that is required for fixing the machine is the drilling of a single hole about 3 inches diameter. The manhole cutter may then be fixed in position ready for work. The apparatus may be applied in any position, either on work in course of construction, or on the plates themselves in the yard. The working pressure is 1500 lbs. per square inch.

HYDRAULIC DRILL AT ST GOTHARD TUNNEL.

In the construction of the St Gothard Tunnel, hydraulic power was successfully employed for the purpose of rock-drilling. The Brandt rotary drill was used at the Pfaffensprung Tunnel on that railway, and more recently at the eastern end of the Arlberg Tunnel. The power was obtained from two high-pressure pumps, which were worked by a turbine pumping into an accumulator at a pressure of 1200 to 1500 lbs. per square inch. A 1½-inch wrought-iron pipe conveyed the water to the machine. Plates 40 and 41 show the construction of the drill, as explained to the Institution of Mechanical Engineers. The drill M is hollow, and is screwed on to the hollow bar Q, which is attached to the plunger I of the ram O, working in the guide cylinder P. Upon this guide (and in one piece with it) is a spur wheel H driven by the worm J. The whole machine is movable from the horizontal tube N (to which it is attached) by the collar piece F. The stop cock Z in the valve-chest B admits the water into a branch pipe leading to the motors D E (about 13 h.-p. each). These drive the worm J, which rotates the drill, at the rate of from 7 to 10 revolutions per minute. By opening the tap Y the water is admitted through the pipe U to the back of the drill plunger

HYDRAULIC MANHOLE CUTTER.

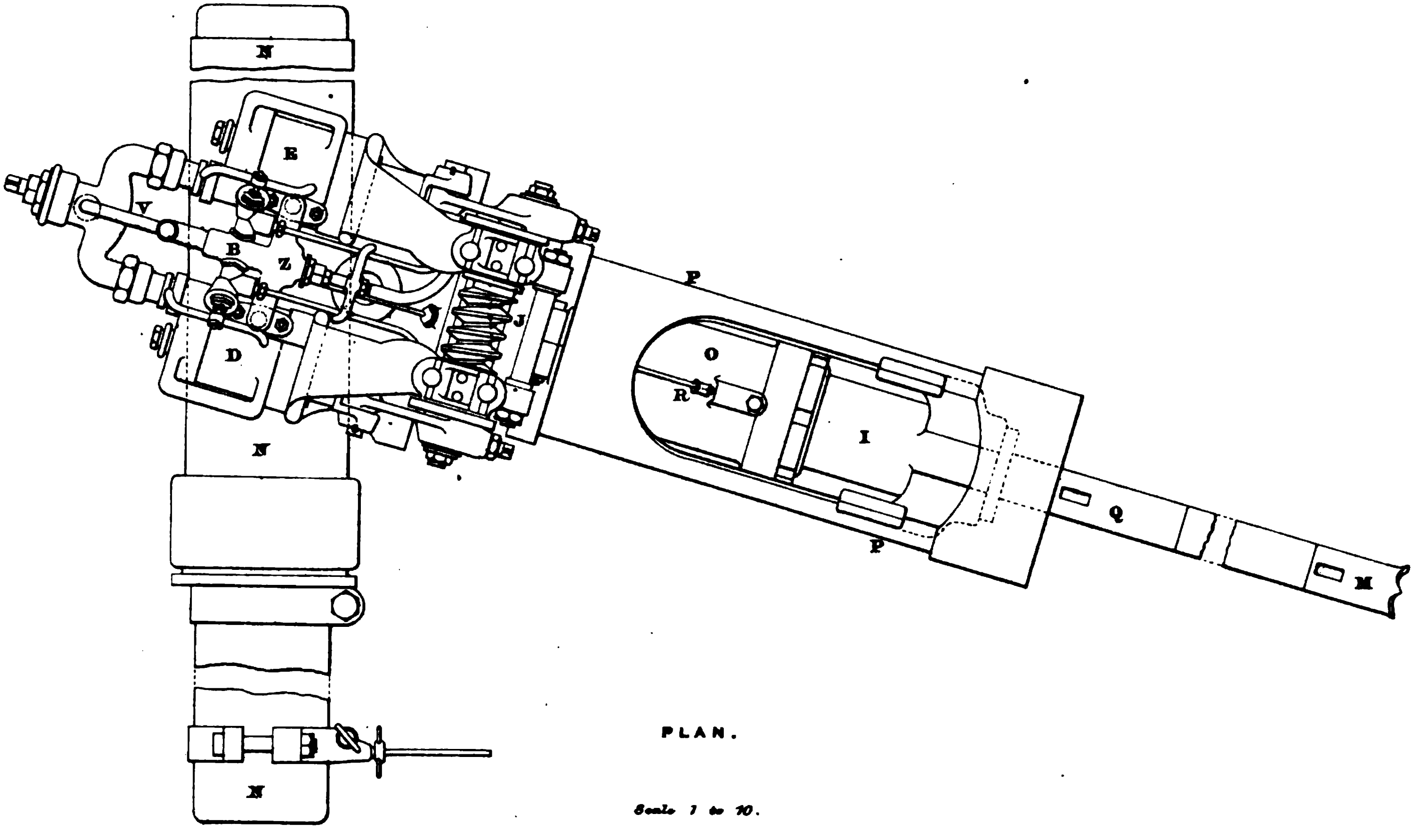




West, Newman Ph.

BRANDT DRILL.

PLATE. 40.

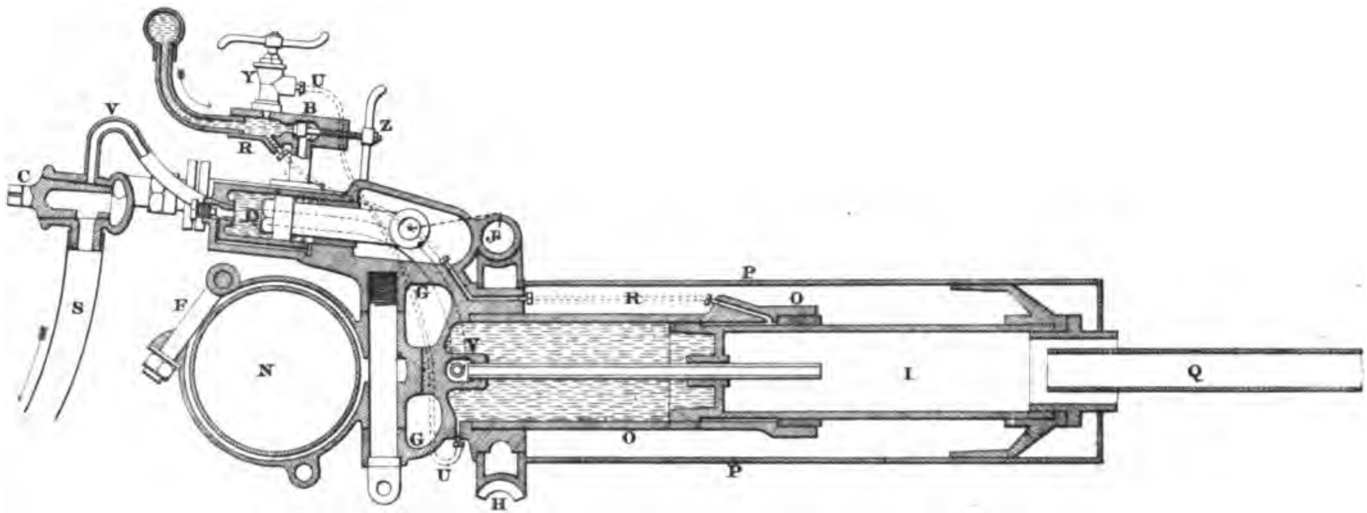


PLAN.

Scale 1 to 10.

Thos Kell & Son Lith

BRANDT DRILL.



LONGITUDINAL SECTION.

Scale 1 to 10

Thos Kell & Son, Lith.

I, thereby pressing the drill against the rock with a force of from 10 to 12 tons. When the tap Y is closed, the water passing through the pipe R drives back the plunger. The extent to which the tap Y is opened regulates the pressure upon the plunger.

The hole can be washed out, to clear it of debris, by closing the cock C in the pipe leading from the motors to the escape hose S. The exhaust water from the engines then passes by the pipe V into a pipe in the cylinder O, and is discharged through the hollow plunger and drill into the drill hole.

The supporting pillar N consists of a tube with a plunger fitted into it. By admitting water-pressure into this tube, the plunger head is forced out against the sides of the heading, by which the pillar is set fast. The plunger can be withdrawn by means of a two-way cock. The pillar and drills are carried on a trolley, and are counterbalanced so as to be in equilibrium when the pillar is not fixed.

The Brandt hydraulic rock drill has been successfully used in the construction of the Simplon Tunnel, and an account of this was given in *The Engineer* for January 1895. The employment of percussive drills worked by compressed air, or of rotary drills worked by hydraulic power, has engaged the attention of those who have to carry out work of this kind, and Messrs Brandt & Brandau adopted hydraulic drills when contracting for the Simplon Tunnel, the makers being Messrs Sulzer Brothers of Winterthur.

Plate 42 is a longitudinal section of the type of drill adopted for the Simplon Tunnel, through the drill cylinder, showing one of the hydraulic motors in elevation. Fig. 4 is a horizontal section through the motors, and fig. 5 shows two drills at work.

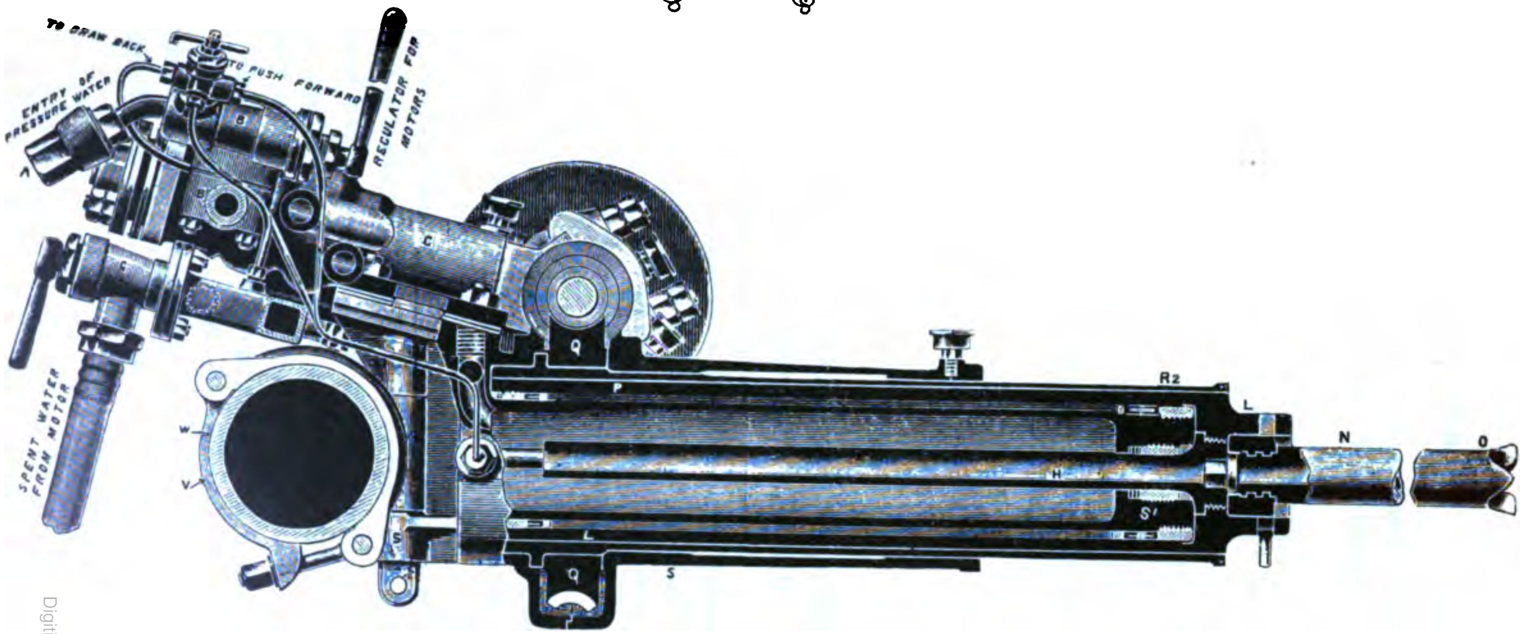
In Plate 42 the post or column on which the drills are carried is shown at W. They can slide along this or be turned to any angle, and are then fixed in position by the clamp V. The fixed plunger S^1 stands on S, which is the base of the machine. On this plunger slides the cylinder L, which through the rod N presses the drill O against the rock which is being

bored. Twin hydraulic motors C and D, working up to 25 h.-p., are fixed by screws to the base S. The pistons of these motors E drive two cranks, set at right angles to one another, which turn the same shaft, on which there is the worm P. This turns the worm-wheel Q, which rotates the cylinder R; and R is connected by grooves and feathers with the pressure cylinder L, so that by its means a rotary motion is given to the rod N and the drill O, which makes from six to ten revolutions per minute.

The cylinder L, and consequently the drill, can be moved forward 2 feet 2½ inches, until it assumes the position shown by dotted lines in figs. 1 and 2. It is then moved back, and N, which consists of a series of pieces, connected by very quick-running screws, is lengthened. These pieces, as well as the drills, are made of drill steel 2⅜ inches diameter, with a ⅞ inch hole running through the centre, to allow water to pass to the end of the drill. This is widened out to 2¾ inches diameter, and has three well-hardened saw-shaped teeth. When blunted, the drills are partly ground and partly milled. The column W, which serves as support for one or more drilling machines, consists of a cylindrical tube, which by hydraulic pressure is very firmly fixed between the sides of the heading. With this object, there is a differential plunger with a piston at the open end of the tube. By means of a two-way cock the pressure water can be made to force the plunger either in or out, so that the column can be securely fixed or loosened immediately.

To work the machine, the column is first secured in position, the drills are then placed as may be desired, being turned by means of the universal joint in their base, and they are then clamped to the column by V. The movable end of the pressure main is then connected to A, and the motors started by means of the valve B. By partially closing this valve, the speed of the motors may be regulated as desired. On the top is a two-way cock for moving the pressure cylinder L, and consequently the drill, backwards and forwards, and there is also a regulator valve for regulating the pressure of the water from the main

Brandt Drill.



so that the pressure on the drill may be increased or diminished according to the hardness of the rock. When this has been set, the advance of the drill is automatic.

The water which has served to drive the motors can still be used to wash out the bore-hole, as it can be passed through the tube H into the hollow rod and the drill, where it serves to keep the teeth from being clogged by powdered stone, which it washes out through the space between the rod and the sides of the bore-hole. The supply of this water is regulated by the cock G, and all that is superfluous passes out through a hose, which conveys it to the drain. The working pressure varies from 375 lbs. to 1500 lbs. on the square inch.

HYDRAULIC RAM.

The hydraulic ram is a machine of great simplicity, which enables the power of a fall of water to be used directly to raise water to a height greater than the fall.

The principle of its action is the elementary dynamic law that the energy of any body in motion will be absorbed, and consequently the body will be brought to rest, by any resistance which opposes its motion if such resistance acts through a sufficient distance.

This principle affords a particularly suitable way of using the power of a fall of water, when the work required to be done is pumping water or compressing air, as the work to be done affords a suitable resistance to absorb the energy of a mass of water. The mass of water is provided by the contents of a pipe of suitable length conveying water from the source of supply to the machine, which is placed in a tail-race. The machine, as ordinarily constructed for small quantities of water, is an iron box in which are two valves, usually called the pulse or waste valve, and the discharge or delivery valve. An air-vessel is mounted over the delivery valve, and the delivery pipe takes off from this air-vessel. Through the waste valve the water

freely escapes into the tail-race for a short time (usually between one and two seconds). The contents of the pipe during this time acquire a certain velocity, and when the pressure on the valve caused by the head due to this velocity is sufficient to raise it, it does so and closes the valve. The water, having then no other outlet but the delivery valve, opens this valve and flows through it against whatever pressure there may be in the air-vessel, until the resistance offered by this pressure has absorbed all the energy of the column of water, and has so brought it to rest. A certain reflux of the water then takes place, which opens the waste valve, and the cycle of operations is repeated. The water so pumped into the air-vessel is discharged through the delivery pipe in a continuous stream.

Machines made in this manner work very well when suitably proportioned, but it has not been customary to use waste valves larger than 4-inch diameter, as the shutting is accomplished with very considerable violence. This is easily understood when it is considered that, even if it were closed by a pressure which continued constant, its velocity would be at its maximum when the valve shuts, and in the actual case the pressure continually increases in amount, so that when the valve shuts, it is many times as great as when the valve began to move.

It has been attempted to reduce this violence by checking the speed of the valve by balance weights, springs, and similar contrivances; but it is evident that it must be very detrimental to the efficiency of the machine to delay the shutting of the valve, because the narrow orifice of the nearly closed valve checks the flow of the water, and so wastes the energy which has been imparted to it in the same way as, by the slow closing of a sluice valve, all the energy of the water flowing in a main may be wasted, and the water may be brought to rest while closing the sluice. This difficulty has, however, been removed by the device, due to Mr H. D. Pearsall, of providing a space into which some of the water

flows during the closing of the waste valve. The velocity of the water escaping by the waste valve is not then increased while the valve is closing, and the valve may, consequently, be closed as slowly as desired, and so without violence; and thus it became practicable to make very much larger valves.

The special object Mr Pearsall had in view was the construction of rams which might be available for the largest engineering works; but this had hitherto not been attained. The difficulties, however, appear now to have been overcome by means of this and various other improvements which have been introduced by him.

PEARSALL'S HYDRAULIC ENGINE.

Plate 43 shows a sectional view of Pearsall's hydraulic engine, of which the following is a general description:—In place of the waste valve D of the ordinary hydraulic ram there is an annular sliding valve *d*, and in order that the opening and shutting of this valve should be made exactly in the pre-determined times, it is moved by a cam *h* which is on a shaft *k* turned by a small auxiliary engine *l*. The cam is so formed that the motion of the valve is dead slow at the instant of shutting, and so closes without any concussion. When the valve *d* is open, the water escapes freely through it into the tail-race, and the water column in the flow pipe B acquires velocity and momentum. As the valve *e* closes, this outlet is cut off, but the flow is not interfered with, as the water can rise freely in the chamber *m*, which is full of air, the air escaping as the water rises through the valve *n*. The quiet, slow closing of the valve, therefore, does not cause any loss of useful effect. The size of this chamber is so proportioned that it is not filled with the water entering it until a short time after the main valve is quite closed. The air valve *n* is

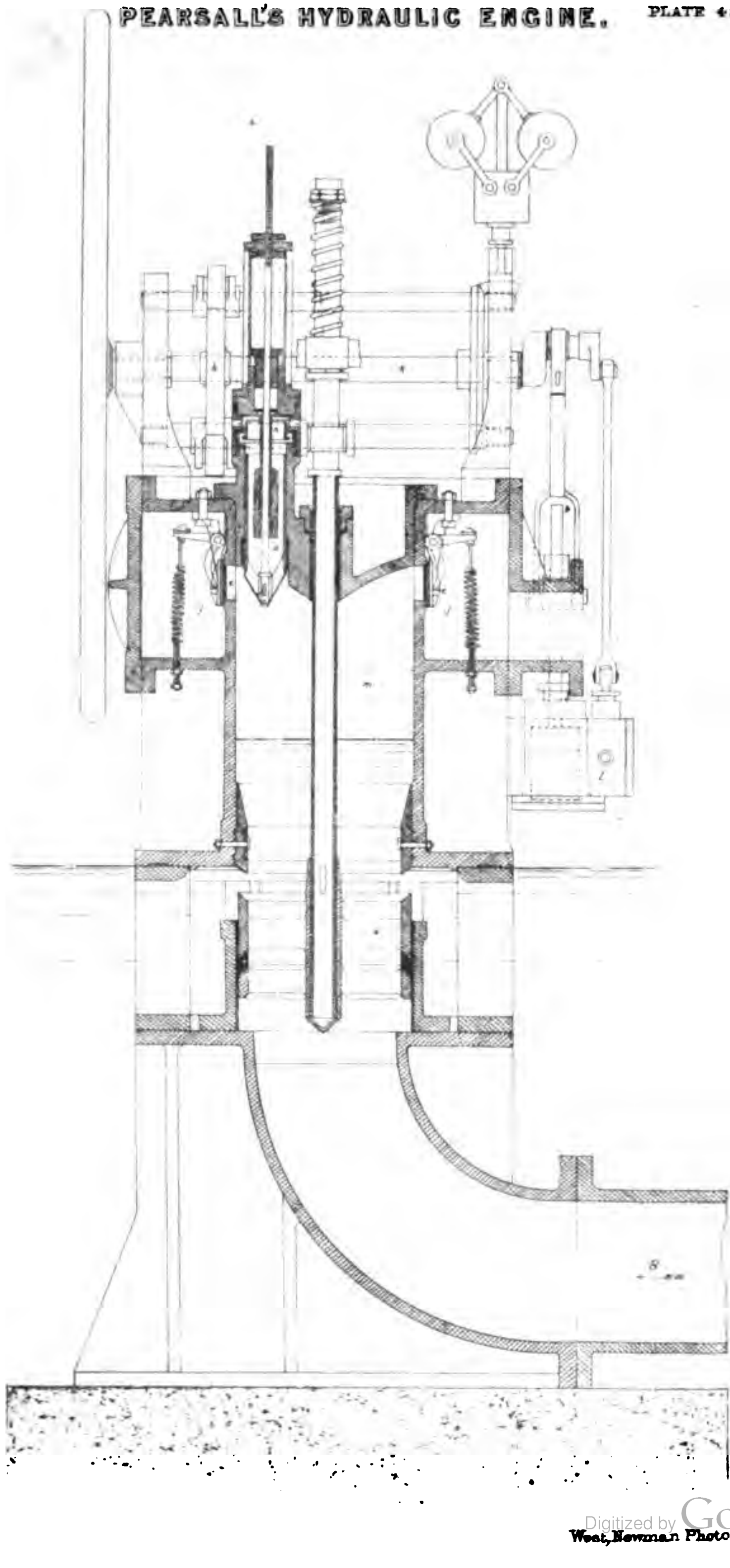
enclosed in a tube *o*; the depth which it projects into the chamber can be regulated by a screw. If it is allowed to project a little into the chamber, the layer of air in the chamber above the edge of this tube cannot escape through the air valve. If, on the contrary, the tube is raised till its edge is flush with the roof of the chamber all the air escapes through valve *n*. Supposing the tube to be in the latter position, the water on filling the chamber opens the valves *e* and flows into the space *f*, which communicates with a larger air vessel (not shown) from which the delivery pipe takes the water to an elevated reservoir. The air valve *n* is closed by the flow of a small part of the water up the tube *o*, past a float attached to the air valve.

Usually the position of the end of the tube O is a little below the roof of the chamber, and then a little air is compressed by the column of water and enters the air-vessel with, or rather in advance of, the water. The object of this is to keep the air-vessel replenished with air, and for use in the little auxiliary engine *l*, which, as already stated, moves the main valve *d*.

The flow of the water past the valves *e* into the air-vessel against the pressure existing there, gradually retards and finally arrests the column of water in the pipe B. This is accomplished without any internal blow, and without any rise of pressure exceeding (except by a few lbs.) that in the air-vessel. This has been proved by indicator diagrams taken by an ordinary indicator from the chamber *m*.

The water having, by this static resistance, been brought to rest after a considerable interval of time, the main valve is again opened, the air valve falls open, and the chamber *m* is emptied of water and again filled with atmospheric air through this valve.

Engines of a similar type have been used also for compressing air. This is accomplished by lowering the tube O still further below the roof of the chamber, and so preventing the escape of a larger proportion of the air which was in the



West, Newman Photo.

chamber. In compressing air, the chamber m is larger or smaller, so as to hold more or less air, according to circumstances—chiefly depending on the amount of the fall. The quantity of air is in all cases regulated with any degree of exactness by the position of the tube O.

Such engines could be used for very large water powers, taking the place of a combination of water wheels with pumps. It will be an advantage to substitute one such simple machine for the combination of two machines, and as it involves only one transformation of power instead of two, a much higher efficiency results. The efficiency actually obtained has been over 70 per cent. in pumping water. In compressing air the difference is even more striking, as these machines have given an efficiency of over 80 per cent.

Herr Pfaehler employed water at the Sulzbach Altenwald Colliery, near Saarbrücken, to transmit the power from a steam-engine at the surface to actuate pumps at the bottom of a shaft 306 yards deep. The steam-engine has a cylinder 53 inches in diameter and 61·5 inches stroke, connected with pressure plungers 9 inches in diameter and the same stroke. These plungers are brought into connection with an underground pumping-engine, consisting of four pressure pumps, with plungers 6 inches in diameter and 66 inches stroke, arranged in pairs, and put in motion alternately by the surface plungers. Between each pair of plungers (which are connected by a crosshead) is placed the working plunger of one of the mine pumps. The engine at the surface transmits the effort of each plunger through its rod tube to the corresponding pair of pressure pumps under ground, and this actuates the working plunger connected with it, either drawing or forcing water, the other pair acting conversely. The water is forced into an air-vessel, and thence through the rising main in one lift to the surface, the power supplied by the descent of water in one column being nearly sufficient to effect its return in the other. The tubes were proved to 100 atmospheres. The working pressure on the underground pumps (due to the difference

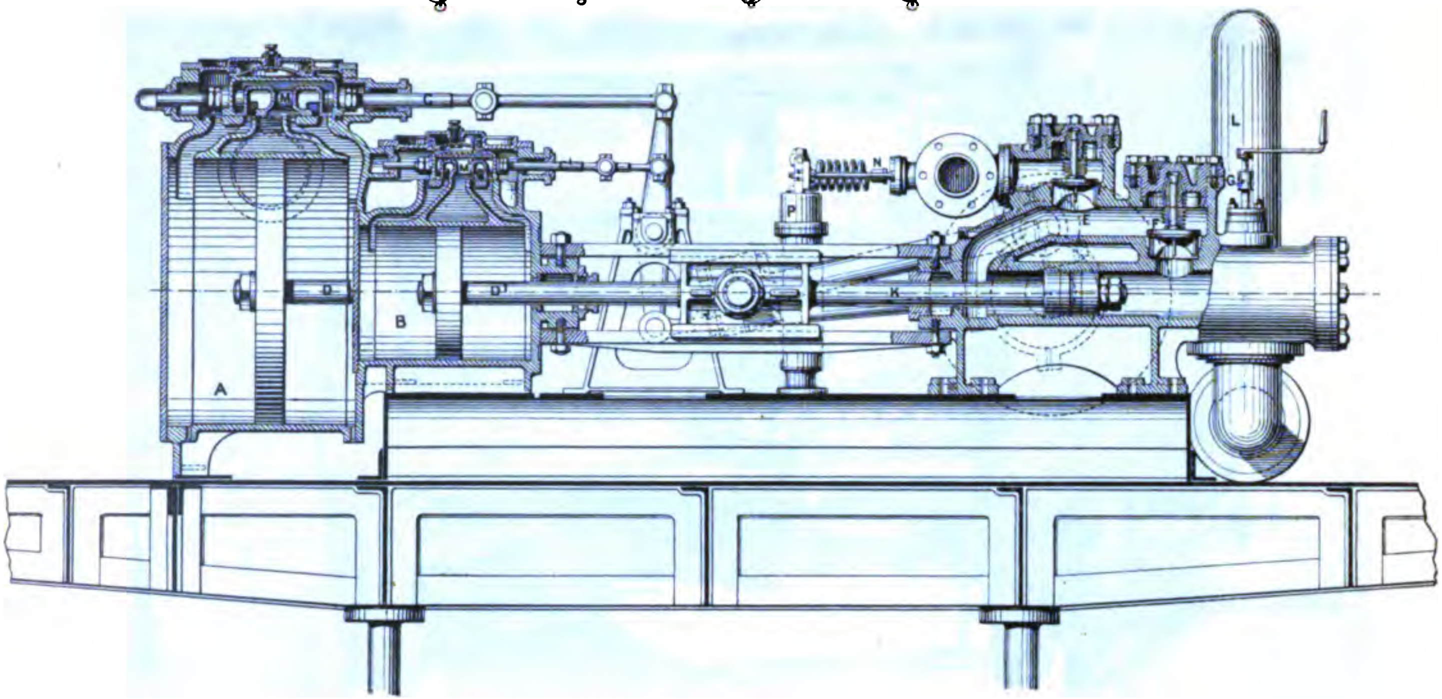
between their areas and those of the pumps at the surface) is 50 atmospheres, and the hydrostatic head in the rods is 27 atmospheres. The total working pressure, including friction, is 77 atmospheres, or about 1155 lbs. per square inch. The engine is worked at a speed of 10 double strokes per minute, the delivery of water being continuous. Careful observations were made in order to ascertain the work absorbed by the friction of the different parts of the machinery, and it was found to be from 25 to 29 per cent. of the total power developed. The effective work of the pumps, at 10 double strokes per minute, was 100 h.-p., and the indicated h.-p. of the engine, with a mean pressure of 20 lbs. per square inch on the piston, was 136 h.-p., which gives a combined efficiency of 75 per cent.

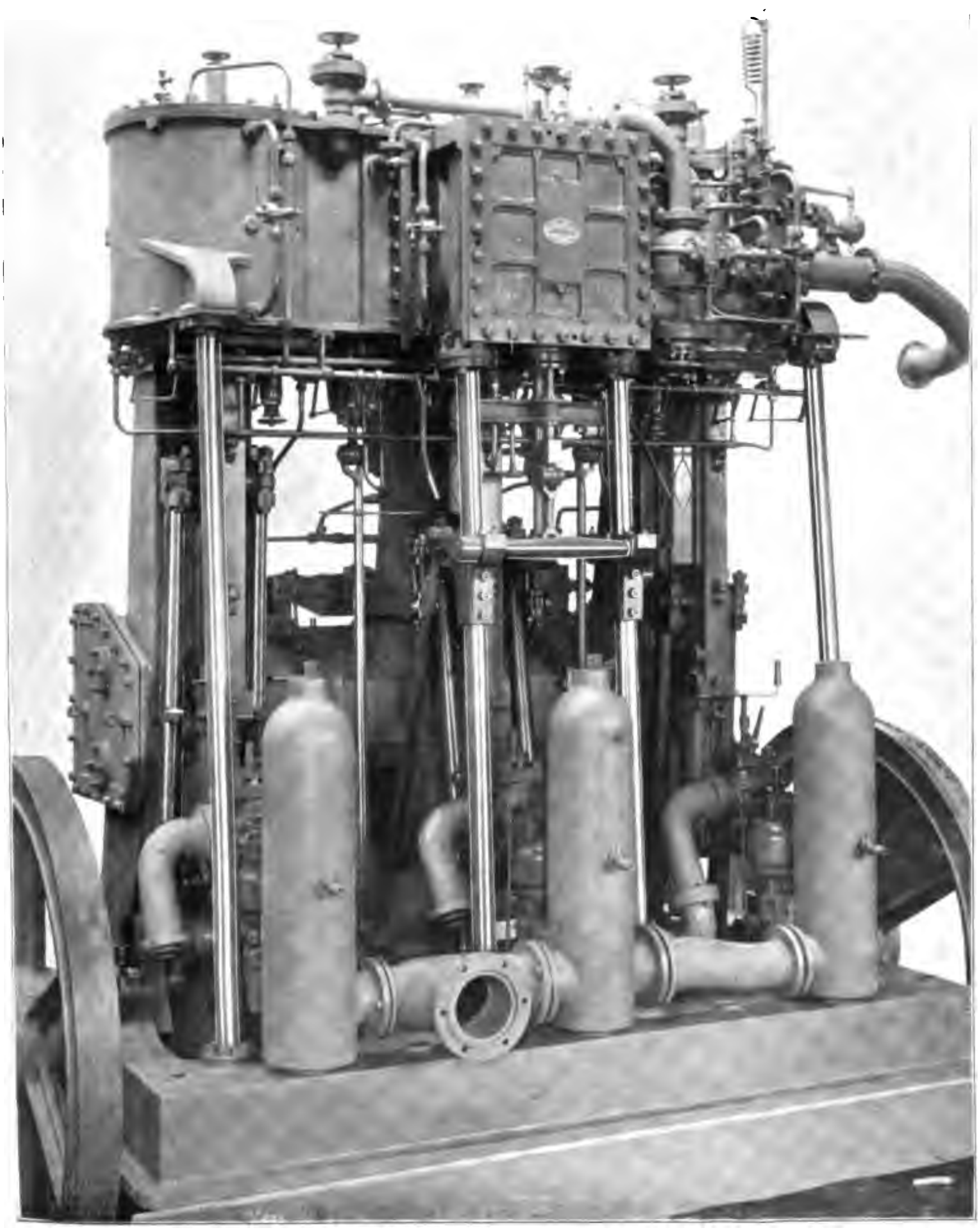
PUMPING ENGINES.

Plate 44 shows a longitudinal section through an Elswick hydraulic engine, which is described in Messrs Lloyd and Handcock's book on *Gunnery* as follows:—

A is one of the low-pressure steam cylinders; B, one of the high-pressure cylinders. The low-pressure piston is connected (by means of two piston-rods D, one passing on each side of the high-pressure cylinder) to the same crosshead as the single piston-rod D, from the high-pressure piston. The crosshead is also keyed to the plunger-rod K. On the forward stroke of the plunger, a charge of water is forced through the first delivery valve F. Half this charge is required to fill up the space which would otherwise be rendered void by the advancing plunger; the other half-charge is forced up the second delivery valve E and into the pressure pipe. On the return stroke, the water on the other side of the plunger is forced through the valve E, and another charge is drawn up through the suction-valve into the pump. The sectional area of the rod K is just

Elswick Hydraulic Pumping Engine.





ELSWICK COMPOUND CONDENSING PUMPING ENGINE.

half that of the pump cylinder, hence the deliveries of the forward and backward strokes are equal. Connecting rods from the crossheads drive a shaft which works the slide valves M M[1] of the steam cylinders by means of eccentric gearing.

Tho hydraulic governor is shown at P, and the relieve valve at N. The handle G is provided as a means of either closing the suction valve or limiting its throw.

Copper pipes were, in the earlier days of hydraulic machinery, exclusively used for the supply system, but the Elswick firm has recently introduced piping of manganese bronze, and as this is a stronger material, its use has had the very important result of reducing the weight of the piping—a very serious item when copper pipes only are employed.

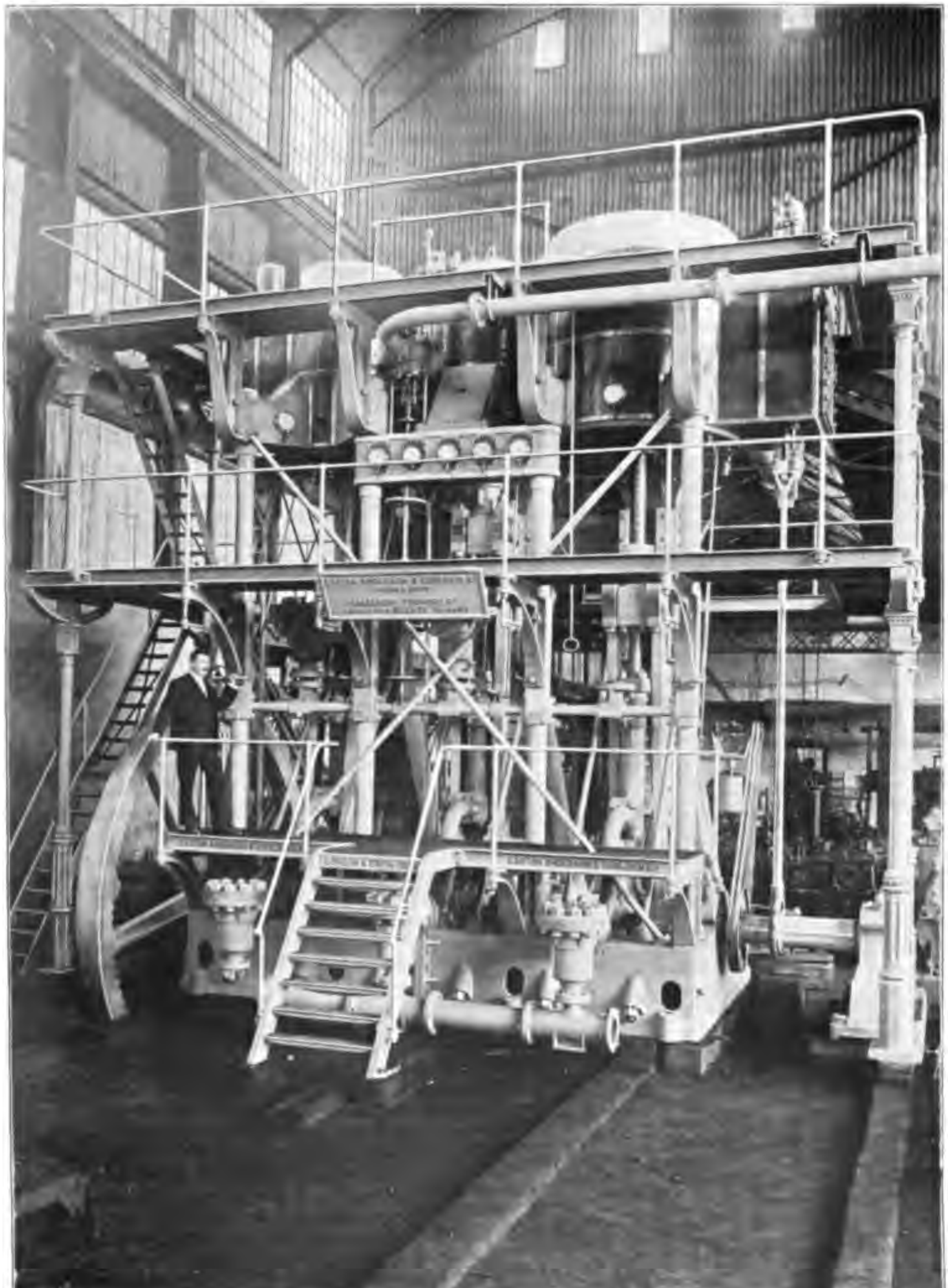
Plate 45 is an Elswick compound condensing pumping engine for producing high pressure hydraulic power. The engine is of the vertical inverted pattern and has three cylinders, one high pressure and two low pressure. In line with each cylinder and coupled direct to its piston rod is a pressure pump, having a plain plunger, each pump being provided with suction and delivery valves and air-vessels on the suction. Pins in the motion blocks at the junction of the piston and pump rods take connecting rods which are coupled to a three-throw crank shaft, the cranks being placed at equal angles. A fly-wheel is provided at each end of the crank shaft. The distribution of steam in the cylinders is effected by slide valves, which are worked by separate eccentrics. The surface condenser is formed as part of the engine framing, and the air and circulating pumps are worked from the piston rods by vibrating levers as in ordinary marine practice. The engine can be arranged as a triple expansion one if desired.

This type of engine has advantages where space is limited, as it occupies less room than a horizontal engine of the same power.

PUMPING ENGINES FOR MINES.

The great depth to which mines are worked at the present time involves arrangements for pumping water from them other than by steam power or by compressed air. Electrical energy transmitted from the surface to pumps in the mine is one method, but this system is beyond the scope of this book to deal with. Hydraulic power is the remaining one which is largely employed, and a good illustration is afforded by referring to a recent installation carried out by Messrs Easton & Co., of Erith, for the Tasmania Gold Mining Company, who wished to increase the depth of their existing shaft from 718 feet to 918 feet, which involved increased pumping power. The difficulty in fixing a new engine was that the shaft would not admit of another set of spear rods being installed. Furthermore, it was desired to make use of a spare set of pumps which were at the mine. The arrangement adopted was as follows:—A hydraulic motor was fixed at the 718 feet level, working by means of spear rods the pumps at the low level, and driven from a new engine at the surface placed in an engine-house some distance away from the shaft, the water being carried to the hydraulic motor in the shaft through solid drawn steel piping, the exhaust being returned to the suction tank at the engine house.

The engine (shown on Plate 46) is of the usual triple-expansion, inverted-cylinder type, having cylinders 25 inches, 40 inches, and 69 inches diameter by 42 inches stroke, the pumps being placed directly below the crosshead, and in line with the piston rod. The crossheads are provided with two gudgeons, and are connected to the crankshaft by double connecting rods of rectangular section. The crankshaft is built up and made in two pieces bolted together by a coupling for facilitating transport. The cylinders at the back are supported on massive cast-iron frames of box section, which also carry the pumps. The intermediate-pressure and low-pressure cylinders are each supported on two steel columns in front. The two middle columns are



HYDRAULIC PUMPING ENGINE FOR TASMANIA.

connected by a cast-iron box girder, which carries the front side of the high-pressure cylinder, and the three cast-iron columns at the back are connected by distance pieces. The cylinders are entirely separate so as to allow of free expansion, and are jacketted throughout. The high-pressure is fitted with a piston valve with internal expansion valve. The intermediate-pressure is fitted with a flat slide valve with an expansion valve on the back; and the low-pressure cylinder is fitted with a double-ported slide valve. The intermediate-pressure and main valve, and the low-pressure valve, are supported by balance cylinders on the top, so as to reduce the stress on the eccentric rods. The pumps and valve boxes are of cast steel, with phosphor bronze rams and valves and seats. The bedplate is cast in halves, bolted together, and is of box section. As the thrust on the guides came rather high up on the back columns, the latter are supported by diagonal tie rods from the front of the bedplate. The front columns are also braced diagonally to prevent vibration. The engine is provided with a large flywheel on each side. The starting gear and all cocks are arranged to be worked from the lower platform, but may also be worked from the second platform.

A complete system of lubrication is arranged for continuous working. The engine is fitted with a throttle valve, which is shut by a knock-out governor when the speed exceeds the fixed maximum. It is also shut when the accumulator on the main reaches its top position. In case the main should burst, the valve is also shut by a weight which is normally held up by a small plunger connected to the delivery pipe. It will be seen that the three platforms fixed round the engine give easy access to all the parts. Steam at 170 lbs. pressure is supplied from four Cornish multitubular boilers, 6 feet 3 inches diameter and 20 feet long. A surface condenser with air and circulating pumps, driven by a small horizontal engine, is to be fixed behind the engine. Provision is also made for exhausting into the atmosphere if necessary. The water is delivered from the pumps at a pressure of 2100 lbs. per square inch.

THE WORTHINGTON PUMPING ENGINE.

Where pumping engines are of the crank and fly-wheel type, the pump-pistons move at a variable speed according to the angularity of the connecting-rod, and the quantity of water that is delivered varies at each instant, from zero at the ends of the stroke, to a maximum about half stroke, when the pistons are moving with the same velocity as the crank-pin. This variable delivery produces a change of velocity in the rising main, and where the engine is pumping through a long main, or one which contains a large body of water, very severe pressures are caused in the pump by the changes of velocity and the inertia of the water. This variation of pressure is compensated for by air-vessels, otherwise the pressures set up in the pump are sufficiently great to fracture the rising main or pump-work. In cases where (through the heavy pressures in the air-vessels) difficulty exists in retaining the air, advantage is experienced in adopting a pump in which the delivery of water is constant, and is not controlled by a crank and fly-wheel. The "Worthington" form of pump fulfils the conditions referred to, the delivery being uniform at all parts of the stroke. There are two pumps, each double acting, the flow from one dovetailing into the flow from the other. The steam cylinders are directly in line with the pumps, and there are no cranks or flywheels. This system has been adopted in pumping oil in America, where, owing to the great length of the mains and their smallness, the head on the pumps is all due to friction. When oil was forced with pumps whose motions were controlled with cranks, such excessive pressures were set up, owing to the change of velocity in the mains, and consequent increase of frictional head, that the pipes were continually bursting.

The Worthington Pump Company, Limited, have recently installed one of the latest Worthington high-duty engines for the East London Water Works, the engine being constructed

by Messrs James Simpson & Co. of London, who have been long identified with Worthington engines. The duplex pumping engine invented by the late Mr Henry R. Worthington (without the compensating system referred to hereafter) has been acknowledged to possess reliability and simplicity, but at the same time it admitted of improvement in the direction of economy in the consumption of steam. To accomplish this through the usual medium of a fly-wheel, or other device, wherein the momentum of a moving mass is utilised for the storing of energy, would be to have deprived the duplex engine of its characteristic advantages.

The Worthington compensating system permits of the cutting off of the steam in the cylinders, and its subsequent expansion to any degree or extent, thus giving to the direct-acting engine the advantages, as regards economy due to expansion, that are obtained by the fly-wheel engine, without in any way affecting the duplex principle.

This improvement marked an important advance in the direct-acting engine, as instead of being confined, as before, to the steam expansion due to the relative ratios of the cylinders, it can now be run at such ratios as are found to be most economical; in other words, any point of cut-off in the cylinder can be used. Plates 47, 48, and 49 show, in general and sectional elevation, the most recent type of engine with this compensating system. The attachment to accomplish this (marked A) consists generally of two oscillating cylinders supported from the main frames, and containing plungers which are attached to the piston rods between the steam and the water ends. These cylinders are connected by pipes, and are filled with water or other fluid, to the surface of which air is admitted at a pressure suitable to the duty to be accomplished, for the purpose of maintaining a constant load at a practically constant pressure on their pistons through the medium of the interposed liquid, by means of an interposed differential accumulator. These plungers act in such a way in respect to the main engine as to resist its advance at the commencement

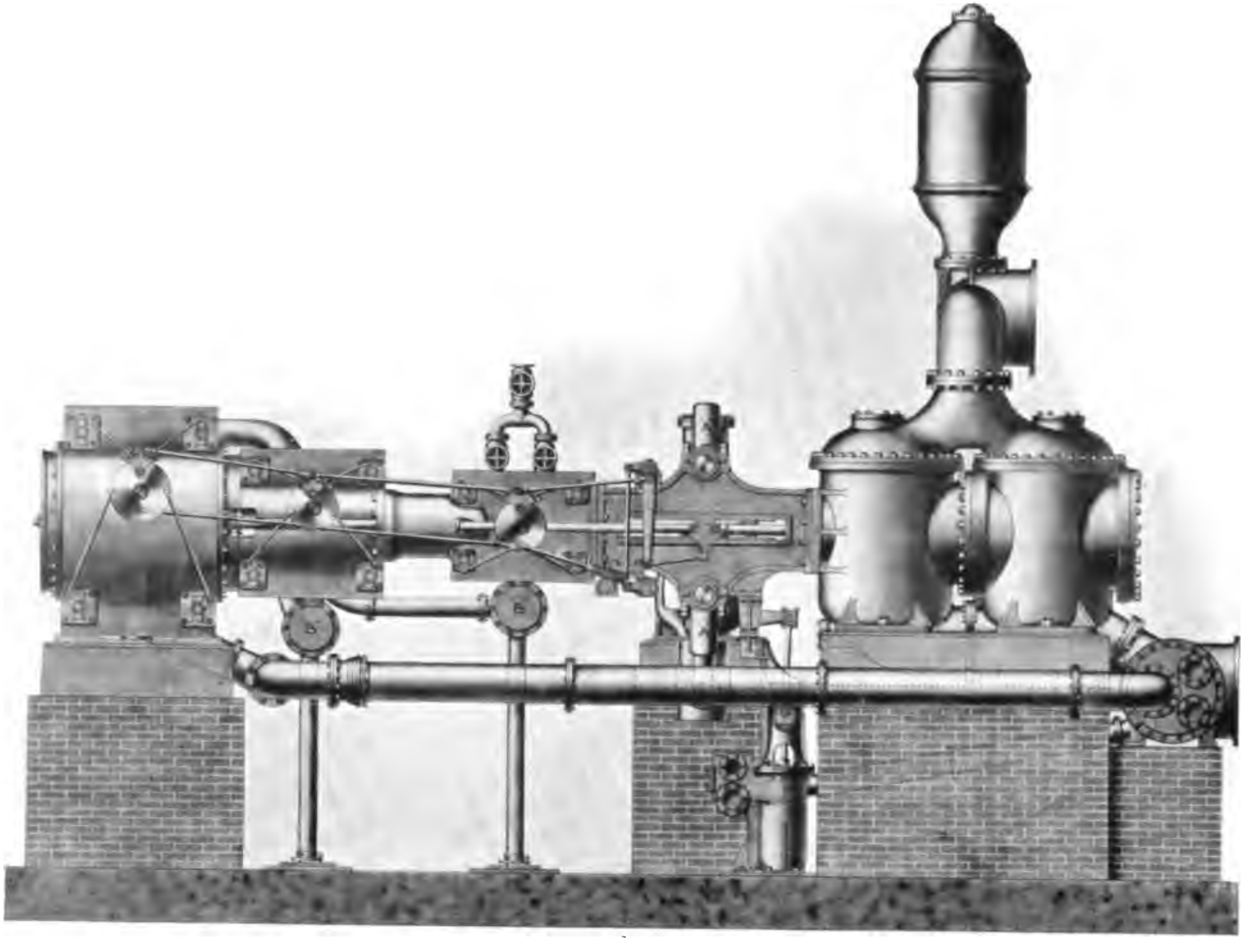
of the stroke, and to assist it at the end, the air meanwhile exerting its unvarying influence at each end of the stroke. The two cylinders act in concert, and, being placed directly opposite each other, relieve the crosshead to which they are attached, and the engine, from any lateral strain.

At the beginning of the stroke, when the compensating plungers form with the piston rod the smallest angle, their influence is greatest, gradually decreasing as the steam pistons advance until mid-stroke, when their influence is *nil*. Having passed the mid-stroke, the pressure within the compensators exerts itself to assist the motion of the engine, increasing at the same ratio as it decreased at the beginning of the stroke. The successive positions of the compensating cylinders are shown by fig. 6, Plate 50. Fig. 1, and the curve, fig. 5, shows the retarding influence in the first half of the stroke and the accelerating influence in the latter half of the stroke, and it will be noticed that this power increases almost in the exact ratio to the decrease of the power of the expanding steam.

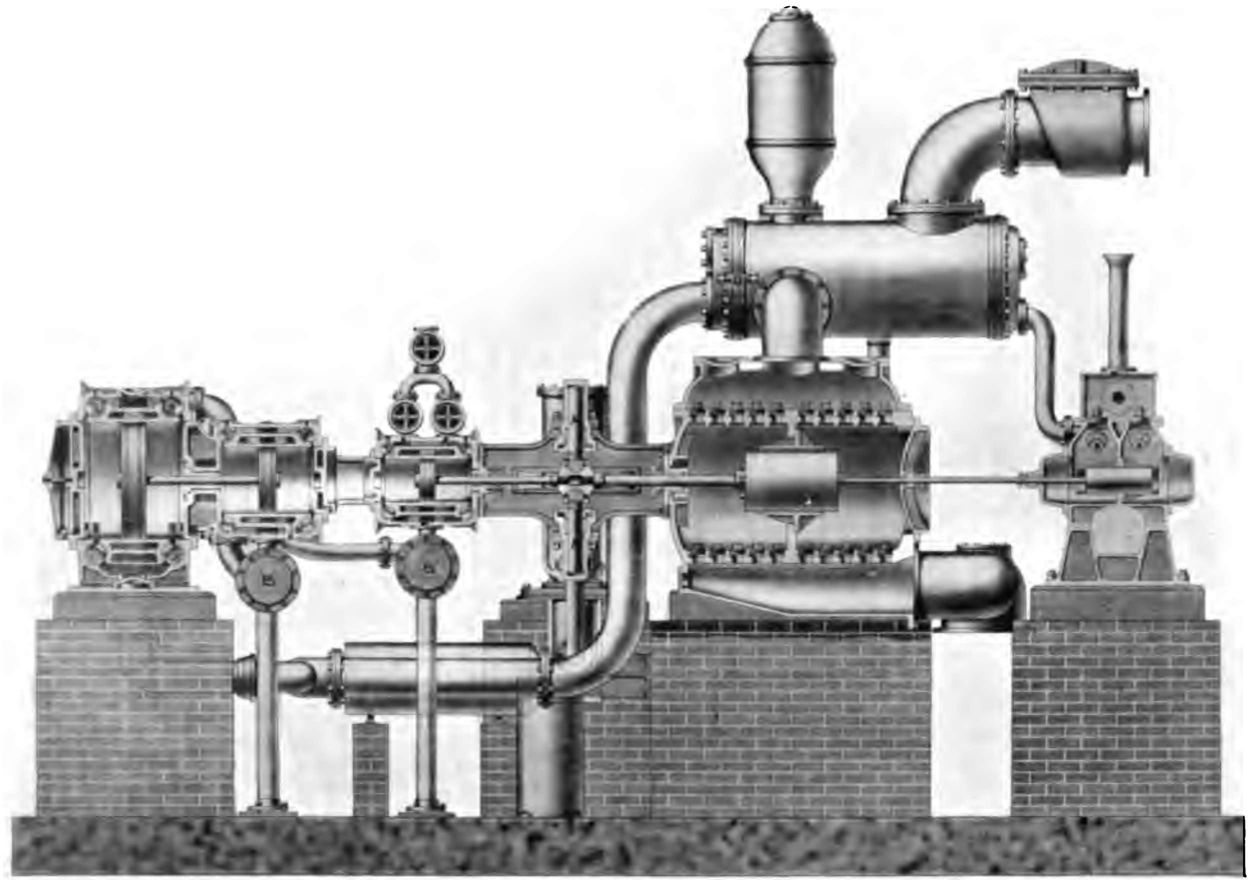
The diagrams from the three steam cylinders are shown by figs. 1, 2, and 3 on Plate 50, the water or resistance diagram taken from the engine being shown by fig. 4, while figs. 7 and 8 show the combined diagram of the steam, the water, and the compensator loads, from which it will be seen that the propulsion diagram shown by the line W W is almost uniform, and, taking into consideration also the effect of the momentum of the moving parts, the result is almost perfect.

It will be seen from an examination of these cards that any number of expansions can be obtained, resulting in the highest economy.

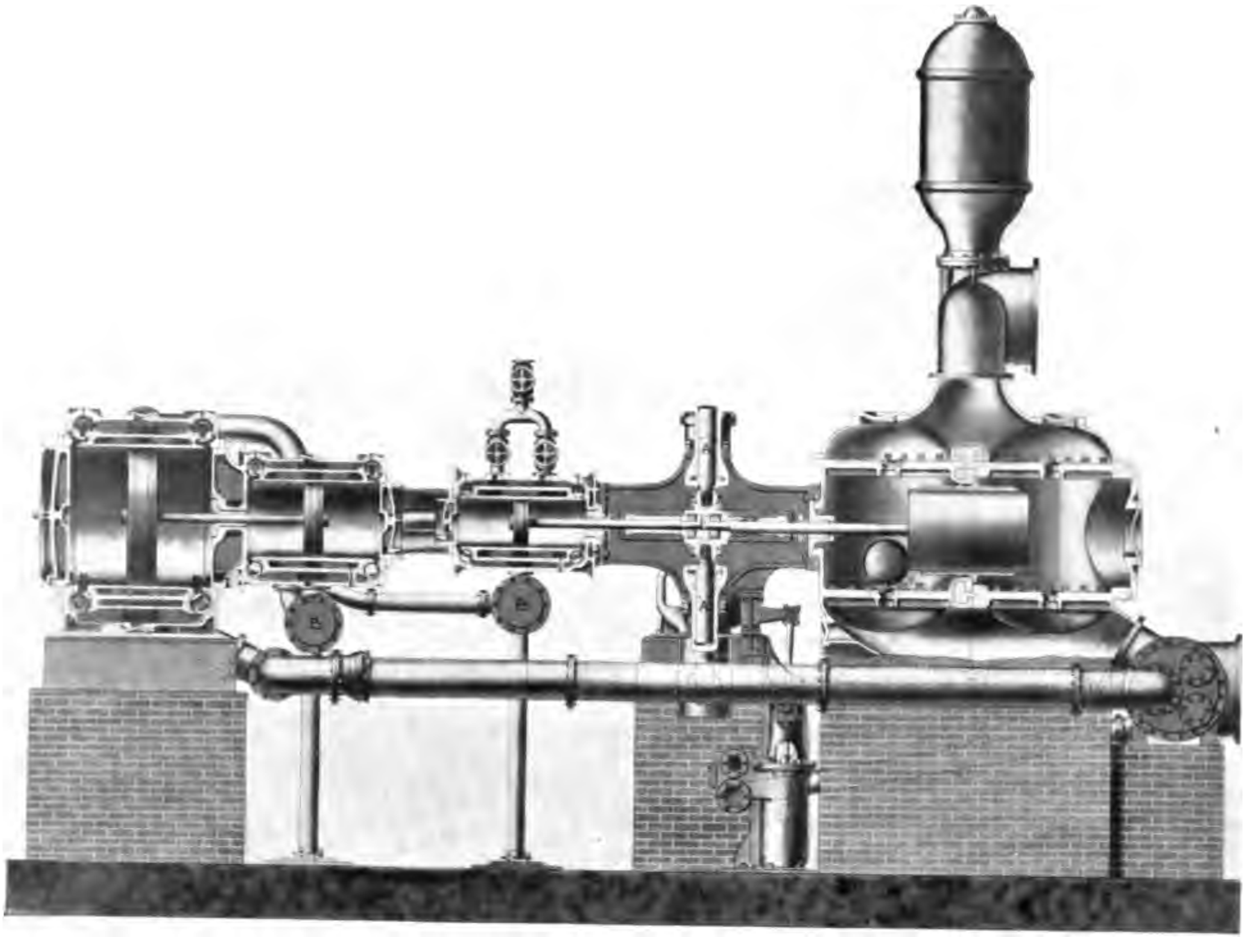
To return now to the compensating system. By thus alternately taking up and exerting power due to the different angle in which their force is applied to the line of motion of the plungers, these compensating cylinders in effect perform the function of a fly-wheel, but with the economical difference that they utilise a pressure of compressed air instead of the energy of momentum. Their action is readily controlled, and their



WORTHINGTON PUMPING ENGINE.



WORTHINGTON PUMPING ENGINE.



WORTHINGTON PUMPING ENGINE.

Worthington Pumping Cylinder Diagram.

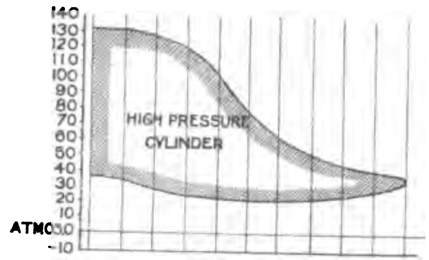


FIG. 1.

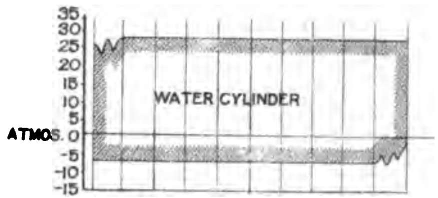
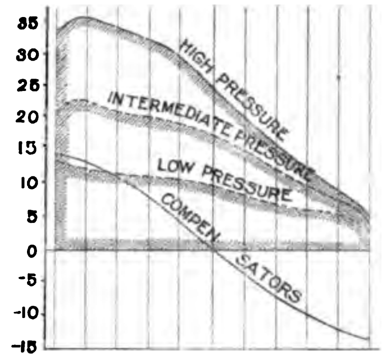


FIG. 4.



COMBINED DIAGRAM OF STEAM CYLINDERS AND COMPENSATORS
THE ABOVE DIAGRAMS HAVE BEEN REDUCED RELATIVELY TO THE SURFACE OF THE LOW PRESURE CYLINDERS

FIG. 7.

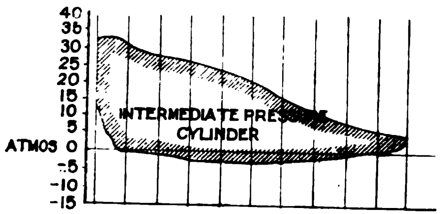


FIG. 2.

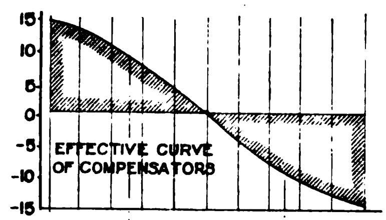


FIG. 5.

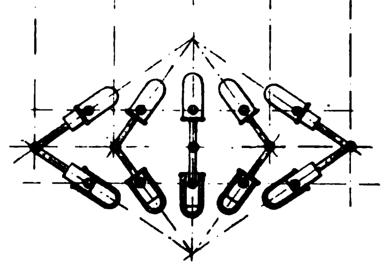


FIG 6

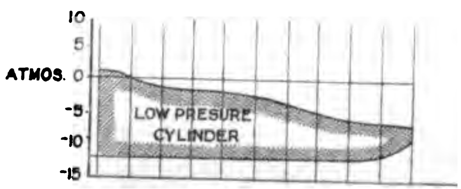
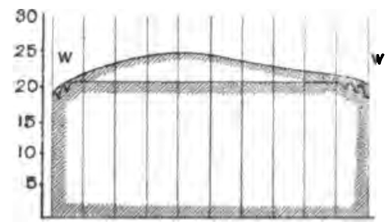


FIG. 3.



COMBINED DIAGRAM OF EFFECTIVE FORCES AND RESISTANCE ON PLUNGER ROD
SAME SCALE AS ABOVE

FIG. 8

power may not only be proportioned to the work to be done, but is unaffected by the speed of the engine; and the same amount of expansion can be obtained by the engine whether running at a speed of 10 or 200 feet per minute, or whether running at 5 or 50 revolutions. This latter feature affects favourably the economy of the engine when applied to any service where the demand is irregular or intermittent.

The force of the compensating cylinders can, at the will of the attendant, be thrown on or off the engine instantly, and without the cut-off mechanism becoming disarranged. In order to limit the size of the compensating cylinders, the pressure on the plungers within these cylinders is produced by connecting this cylinder through hollow trunnions with a differential accumulator, the upper part of which is in direct connection, through the air chamber, with the water pressure. By this means the water pressure within the compensating system is multiplied to such an extent as may be found desirable. The pressure in the force main results in a uniform propulsion of the water column, and an absolute control of the speed of the engine, without recourse being had to any automatic governor or other devices. Should the force main or distributing pipes burst from any cause, no accident can occur to the engine itself, as the loss of pressure in the main would result in a corresponding loss of power in the compensators, and, should the pressure be entirely withdrawn, the engine would be unable to complete its stroke and would come to a dead stop.

These cylinders are arranged with the high-pressure steam cylinders bolted directly to the cradle nearest the pump end, with the intermediate cylinders next, there being an intervening space between the high and the intermediate-pressure cylinders. The low-pressure cylinders are bolted directly to the intermediate cylinders, and are thus at the extreme end of the pump.

In the arrangement of piston rods, it will be seen that the high-pressure piston rods are directly coupled to the pump rods. Between the high-pressure cylinders and the pump end there is

a crosshead, to which are attached two side rods connecting to the low-pressure pistons. The piston rods between the intermediate and low-pressure cylinders work through long metallic sleeves, made an exact fit to the rod, thus doing away with two stuffing boxes and the friction attendant upon them. These sleeves, after many years' experience, have been found most satisfactory. This arrangement of the piston rods permits of the examination and withdrawal of any of the steam pistons without in any way dismantling the engine itself.

The steam, in passing from one cylinder to the next, goes through re-heaters (marked B) situated below the high and intermediate cylinders, where it is re-heated by live steam at full boiler pressure. These re-heaters are fitted with brass tubes, the heating steam passing through them being in connection with the steam jacket system, and passes in succession through the steam cylinder jackets and re-heaters.

The steam valves of these engines, instead of working upon the usual seat, forming part of the cylinder casting, work upon separate cast-iron linings carefully turned out and forced into the main cylinder casting. This system enables their withdrawal and repair in the event of the lining becoming cut. The steam passages in these liners are carefully cut out on a milling machine to standard gauges and templates, as are also the edges of the valves themselves, thus ensuring an absolute uniformity and interchangeability of all the valves in the engine, which would otherwise be impossible, owing to the liability of the ports to shift their position in casting.

The steam pistons are fitted with adjustable packing rings made in segments, and expanded by means of an undulating flat spring placed between the ring and the body of the piston. The rings are carefully scraped into position, and are made as light as is consistent with proper strength and ample bearing surface, so as to reduce the friction and wear to a minimum.

The valve motion of these engines is a modification of the Corliss type, made specially applicable to direct-acting pumping engines, and with certain improvements which are only pos-

sible with this type of machine. The cylinders are arranged with two admission valves on top, one at each corner, which also serve as cut-off valves, and two exhaust valves at the bottom, placed at either end of the cylinder. The four valves are operated from a central wrist plate, supported from a bracket bolted to the steam cylinder. The wrist plate is moved through the medium of links and rockshaft from the crosshead to the opposite side, in the ordinary manner of the duplex valve gear. The exhaust valves are opened and closed by links connecting the cranks on the valve spindles directly with the wrist plate.

The steam admission and cut-off valves, on the other hand, are connected by links from their cranks to a secondary four-arm crank, which is fulcrumed on the wrist plate, but which receives its motion from its own side of the engine. This gives the effect of a broken-link or knuckle-joint connection between the admission valve and the wrist plate, which results in the valves being opened by the motion of the wrist plate proper as derived from the opposite side of the engine, and closed by the secondary motion carried through the fore-arm crank, and derived from their own side of the engine.

By this arrangement the cut-off is as rapid as can be desired, and being without trip motion, releasing, or other devices, the valve gear is exceedingly simple, and capable of very wide adjustment. The point of cut-off may be varied at will, and each valve can be altered separately while the engine is in operation, by the simple turning of a screw.

The operation of the valve motion is very easy and noiseless, while being accessible at every point, as it is all placed on the outside of the engine, having none of the parts between the steam cylinders.

COMPENSATING CYLINDERS.

These consist of four cast-iron or steel cylinders, which are provided with large trunnions carried in bearings on the main

engine frames. The compensating cylinders contain single-acting cast-iron plungers which have chilled and ground surfaces. These plungers are screwed into T heads or thrust pins which work in bearings carried on the cross-head attached to the main piston rod. Thus, with the motion of the piston rod, the compensating cylinders are oscillated back and forth by means of their plungers, which run in and out of the stuffing boxes.

The compensating cylinders are always under constant pressure, hence there is an equal load on the compensating plungers at all points of the stroke, and the actual effect of this force on the piston rod of the engine is determined by the various positions of the compensating cylinders during the stroke. The closed ends of the compensating cylinders are connected by ports which pass through the trunnions to a central distributing pipe which is in connection with the differential accumulator.

The stuffing boxes of the compensating cylinders through which the compensating plungers work, are packed with metallic packing, which may be considered as practically permanent.

The proportioning of the compensating cylinders to the horse-power of the engine is such that in all Worthington engines practically the same pressure is carried in the high-duty attachment; hence all these parts are reduced to a standard form of construction, the only difference being in the diameters necessary for different horse-powers.

Professor John Goodman has given considerable attention to the conditions which obtain in the working of a plunger pump, and he conducted a series of experiments at the Yorkshire College, Leeds, with an ordinary plunger donkey pump, such as is in common use for feeding boilers. The results were brought before the Institution of Mechanical Engineers in February 1903. He referred to difficulties that used to be experienced in the early days of the petroleum industry in America, in pumping the oil through long pipe lines, and that the problem was

solved by the introduction of the Worthington engine, which minimises the fluid shock in the pipes by means of the direct-acting or free-piston pump, in which the pump plungers gradually come to rest and to pause at each end of the stroke, thus preventing any sudden change in the velocity of the fluid. When "shock" pressures, however, are set up, even with short lengths of pipes, many problems arise which are much greater than can be accounted for by ordinary theories. When a pump is fitted with an air or vacuum vessel on the suction pipe, many of the phenomena dealt with in this paper disappear, but the object of the investigations was to study the effects of "water ram" in pipes, and also how the "slip" or the "discharge coefficient" of a pump not fitted with a vacuum vessel was affected under changes of outlet, speed, and length of suction. By the "slip" is meant the difference between the volume of water actually pumped, and the volume displaced by the pump plunger, a common assumption being that "slip" causes a small loss attributable to leakage, or to air entrapped in the water. In the experiments recorded in this paper there were circumstances under which the pump actually delivered more than 50 per cent. more water than that calculated by the displacement of the plunger, although, of course, the useful work done cannot be greater than that indicated in the pump barrel, less friction.

In the case of a pump having a suction pipe of the same diameter as the plunger, the water will, under normal conditions, move with the same speed as the plunger, and will be accelerated and retarded in the same manner. Hence the mass of the water in the suction pipe may be regarded as a part of the mass of the reciprocating parts, and therefore the suction or negative pressure required at the beginning of the stroke to accelerate the water, and the positive pressure set up at the end of the stroke when the water is retarded, can be readily calculated. If the area of the suction pipe be less than that of the plunger, the water in the pipe will move with a correspondingly higher speed, and the above-mentioned pressure (per

unit area) will be increased in the direct proportion of the area of the plunger to the area of the pipe. Although many of the data recorded in this paper may apply only to a small pump like the one experimented with, they deserve to be studied.

DAVY'S PUMPING ENGINES.

Fig. 56 shows pumping engines made by Messrs Davy Brothers of Sheffield. These engines are of an improved three-

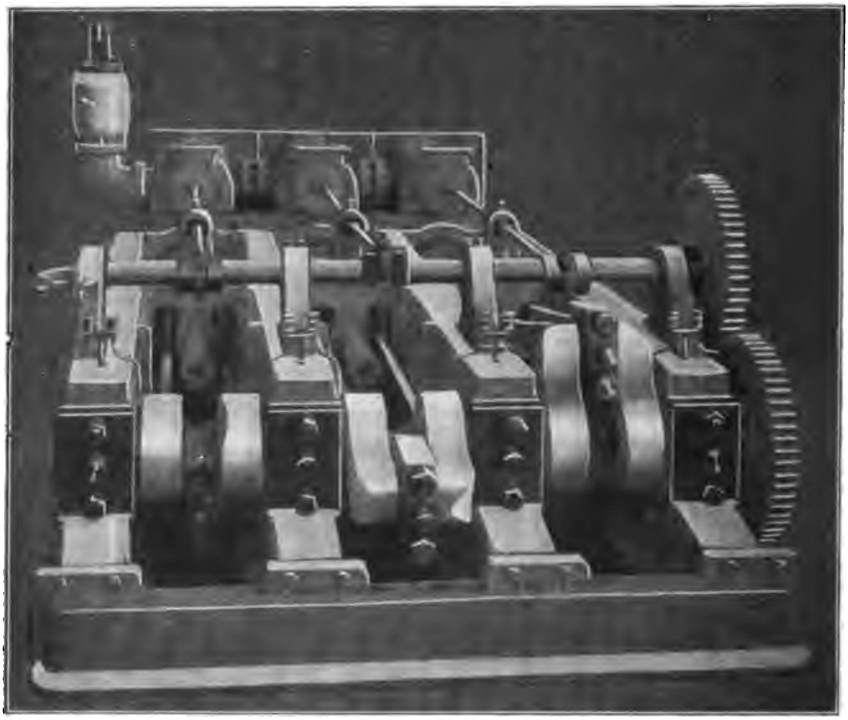


Fig. 56.

cylinder type, which the makers consider offer many advantages over the fly-wheel type. The steam cylinders are three in number, coupled up by connecting rods to a three-throw crank-

shaft, the tail rods of the cylinders being coupled direct to the three pump plungers. The three cylinders enable the engine to have a very equal turning moment, and, at the same time, the valves can be set with an early cut-off. The throttle valve is connected to a handing lever in front of the press attendant, who can not only instantly stop and start the pumps, but can regulate the speed to exactly suit the requirements of the work under the press, whereas with the ordinary fly-wheel pumps the engine must be started some time before forging actually begins, and must be kept running until the end of forging operations. With the three-cylinder arrangement the pumps will be standing probably quite one-half of this time, this alone resulting in a considerable saving of steam.

In the most recent type of this press the pumps are only one-half to one-quarter the capacity required by presses fitted with ordinary valves and working at the same speed, as by an improved form of valve the press-head can be lifted about 12 inches for every revolution of the pumps, and can be lowered at the same speed on to the work, where it can rest with its own weight, or can be made to continue its stroke under pressure from the pumps without pause. The whole of these operations are controlled by one single lever and two mitre-seated valves, the whole arrangement being of the simplest form possible.

The supply water to the pump suction is connected to an air vessel under a pressure of about 60 lbs. per square inch. This low-pressure water is also connected to the main press cylinders when the press is being raised or lowered. This arrangement of supplying pressure water to the pump suction enables very much smaller pumps to be used, as it enables them to run at a very great speed without shock. It has, moreover, a further advantage, which is that the whole of the water used is sealed and never comes in contact with the atmosphere. It remains, therefore, perfectly free from dirt or grit, a matter of no small importance in places where forging presses have to work, in maintaining the valve faces free from wear, and in prolonging very materially the life of the packing leathers.

THE GREATHEAD SHIELD.

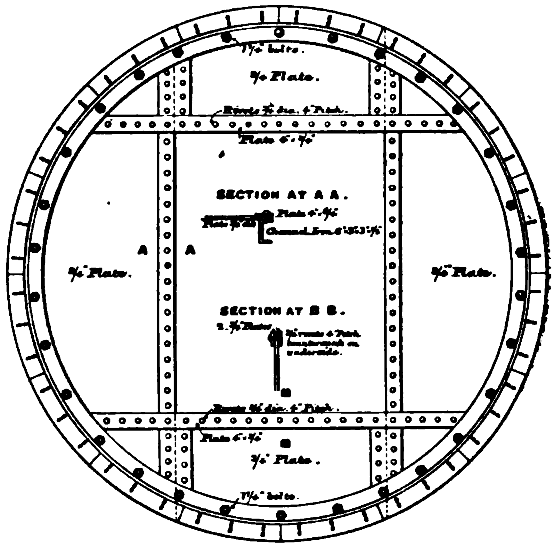
The construction of tunnels through water-bearing formations has been greatly facilitated by the adoption of a lining of cast-iron or steel segments, which, when completed, form a continuous cylinder, in the execution of which work hydraulic power plays an important part. The late Mr Greathead's name will always be associated with the introduction of the shield (as it has been termed), the first use of which was in the construction in 1869 of the small tunnel at the Tower, designed by the late Mr Peter Barlow. Following this, a short length of tunnel, 8 feet in diameter, was constructed in 1870 for the Broadway Pneumatic Railway in New York, and another was afterwards made in Cincinnati. These, although not subaqueous, were carried out by means of shields (of boiler plate), similar to the Tower Subway, and propelled by small hydraulic presses. Cast segments are employed in recent works. In a paper that was read at the Institution of Civil Engineers in 1895, by Mr Greathead, an interesting historical account is given of the system, and a description of the work in connection with the construction of the City and South London Railway, which was at first proposed to be made from King William Street in the City on the north, to the "Elephant and Castle" at Newington on the south. Subsequently, parliamentary powers were obtained to extend the line to Islington on the north, and to Stockwell and Clapham Common on the south. Reference can only be made here to the work relating specially to the construction of the tunnel by the shield, in which hydraulic power was so advantageously employed for forcing the shield forward, whilst compressed air prevented water entering the tunnel.

The first shield of the eighteen used on the City and South London Railway was almost identical in its design and construction with that shown in figs. 57–59, which represent a shield for the 10-foot 6-inch tunnels constructed between the

"Elephant and Castle" and Stockwell. It consists of a cylinder 5 feet 11 inches long, of steel plates in two thicknesses of ½ inch, each rivetted together to break joint with rivets countersunk on both sides. This cylinder was bolted to a strong ring of cast iron at the front end, and to this ring were bolted the plates and channel-bars forming the face, and the adjustable steel cutters. The latter were so attached that they could be adjusted to cut out the excavation to the same diameter as

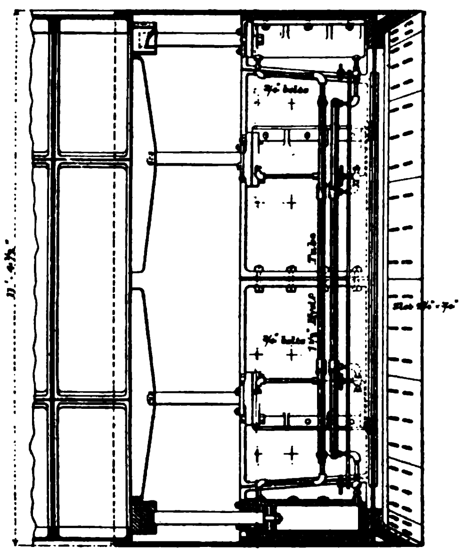
BACK ELEVATION OF SHIELD.
Fig. 57.

or wider than, the steel cylinder following them; the latter provision being necessary for passing round curves in any direction either horizontal or vertical. In the face was provided a rectangular opening with iron doors upon rollers for sudden closing. It was, however, found in practice almost impossible to maintain these doors in working order, so they were subsequently removed and reliance was placed on timbers cut and kept ready for dropping into the channels placed for the purpose at the sides of the doorway. These were always used when work was suspended at a face, or when wet material was



ELEVATION SHEWING CUTTER.

Fig. 58.



SECTION OF SHIELD.

Fig. 59.

encountered pending the provision of appliances for dealing with such material. The inside of the cylinder in rear of the face was lined with massive cast-iron segments; and to these were bolted, as shown in fig 57, six hydraulic presses of 6½ inches diameter. The presses were connected with two hand-pumps, for forcing the shield forward. The same pumps served also to run the rams back into the presses. To the projecting ends of the rams were attached long shoes for carrying the pressure on to the solid part of the cast-iron tunnel-lining without bringing any bending strains upon the rams, or undue pressure on the tunnel-flanges. The rear end of the shield, for a length of 2 feet 8 inches, consisted only of the steel cylinder; and within this the cast-iron segments forming the tunnel-lining were put together.

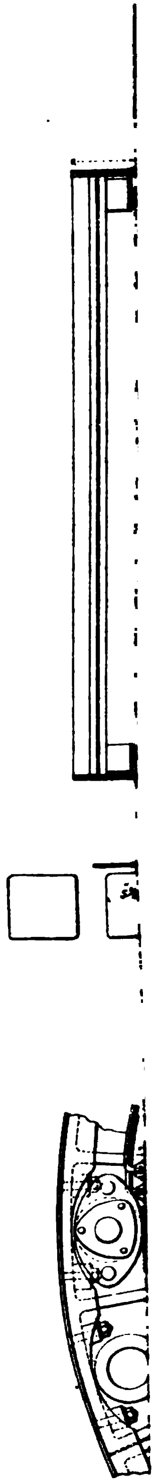
HYDRAULIC PRESSES IN THE SHIELD.

The hydraulic presses in the shields used in the City and South London Railway were supplied with water from two cisterns placed inside the shield by hand-pumps, one on each side of the platform in the shield, fig. 57. These hand-pumps generally forced the shield forward in about ten minutes, overcoming the skin friction and the resistance due to wedging and cutting the clay in the face. The pressure varied between 500 lbs. and 1800 lbs. per square inch, depending upon the number of presses in use, the projection of the cutters, and whether the tunnel was being driven in a straight line or on a curve. A reversing valve enabled the rams to be driven back by the same pumps either singly, in groups, or all together.

The excavation is effected by forcing forward the shield by the hydraulic rams until a space equal to its own diameter is formed, and at each advance a length is completed equal to one of the rings of the lining of the tunnel. Several descriptions of tunnels which have been constructed by means of the

Greathead shield are recorded, but reference will be confined to the most recent one, which is the Baker Street and Waterloo Railway, particulars of which were given to the Institution of Civil Engineers in 1902, by Mr W. C. Copperthwaite and Mr A. H. Haigh, and in a paper by Mr Hardington A. Bartlett in 1903.

The following is a description of the shield that was used for constructing the tunnel under the Thames through very open ballast charged with water. Its outer casing consists of a steel cylinder 13 feet in external diameter, having the lower part in front cut away, in curved form, from a maximum height at the cutting edge of 3 feet, leaving a hood or cover above an open invert. The middle portion covers the rams, and the back part forms the tail or erecting-space for the iron tunnel-rings. The edges, at the front of the hood, are bevelled at an angle of 45° to form a cutting edge. A circular box-girder, 10 feet 1 inch in internal diameter, together with a middle vertical girder within it, form the main frame or rib of the shield. The several thicknesses of steel skin at the hood are connected by nine circular rows of rivets 1 inch in diameter and of 6-inch pitch, with their outside heads countersunk, and one row of 3-inch pitch close to the bevel of the cutting edge. The six longitudinal joints of one layer of the skin break with those of the adjacent layers. Cover-strips run the whole length of the shield over the outermost six longitudinal joints. Nine gussets connect the side plate of the box with the skin of the shield. The whole length of the shield is 9 feet 8½ inches; which may be divided into: main body 5 feet, tail 2 feet 6 inches, hood 2 feet 2½ inches. Within the main body, behind the circular girder, is the cast-steel ring bearing the fourteen hydraulic rams, each 6 inches in diameter, clustered at the lower parts and set in pairs laterally (figs. 4 and 5, Plate 51). Ordinarily the lowest four were not brought into use, six or more of the remaining ten being suitable and sufficient for driving the machine. Each ram was capable of being actuated independently. The ram-cylinders, of cast steel, are 1½ inch



thick, and have a stroke of 20 inches. All the cylinders, pipes, valves, and connections were adapted to stand a hydraulic pressure of 2400 lbs., and were tested to 3500 lbs., per square inch. Working-pressure was supplied to the rams by an intensifier, having a cylinder 7 inches in diameter, fed by the London Hydraulic Power Company's water from their mains in the Embankment, at about 800 lbs. per square inch; and the pressure on the piston was transmitted by two plungers 3 inches in diameter to the water in communication with the rams. The calculated multiplication is $4\frac{4}{9}$, and an effective result of 3 is allowed. The usual average pressure in the rams when driving was about 1300 lbs. per square inch. Mr Bartlett describes the method of constructing the tunnel of the same railway in London clay as follows:—

The Greathead shield consists of three main parts:—The cutting edge; the skin; the cylindrical jack casting.

The cutting edge is of cast steel made in three sections bolted together, and is of slightly larger diameter than the skin of the shield in order to facilitate the progress of the shield through the clay.

The skin is composed of a half-inch cylindrical steel plate, 6 feet long, made in three sections with butt-joints, and half-inch cover plates, extending from the cutting edge, to which it is fastened with countersunk set screws, to about 2 feet 9 inches behind the back of the jack castings, forming what is known as the "tail" of the shield. The object of the tail is to support the ground and protect the miners whilst erecting the iron.

The ring of jack castings is made in six sections bolted to each other and to the skin and cutting edge, hard wood packings being used in the horizontal joints.

Besides affording a firm foundation for the jacks, these castings greatly strengthen the shield, and, indeed, are its chief support.

Between the jack castings and the cutting edge is a steel diaphragm consisting of two $\frac{1}{2}$-inch plates, the duty of which is to give stiffness to the shield and maintain it in shape.

The shield is driven forward by hydraulic rams or jacks, eight in number, each 7 inches in diameter; the requisite pressure being obtained by means of an air-engine or intensifier, fixed to the shield, which is supplied with air at a pressure of 60 lbs. per square inch, and which intensifies the pressure, forcing water into the rams at a ton (2240 lbs.) per square inch.

A flexible pipe connects the compressed-air main in the tunnel with the shield, and the intensifier draws its water from two tanks fixed on the shield, one on either side.

The shield is fitted with an oak grouting rib made in sections, having strips of leather nailed to it at the outside edge, and projecting about ½ inch beyond the oak all round. This ring is held in position by the rams, and serves two purposes: firstly (as its name implies), to keep the grout in whilst grouting up; and secondly, to distribute the pressure of the rams evenly over the segments of the tunnel lining.

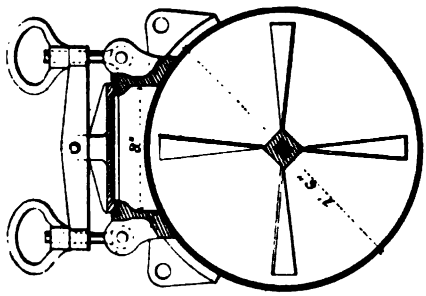
As the shield advances it clears out a circular space somewhat larger than the outside diameter of the steel lining of the tunnel, thus leaving an annular space which is filled with a grouting mixture consisting of three of blue lias lime to one of clean sharp sand. The grouting machine is shown in figs. 60 and 61.

The grout is mixed to a proper consistency in the cylinder, the lid of which is then closed and made air-tight. Compressed air is brought from a compressor by a small pipe into the machine, and the grout is forced out and discharged through a flexible hose into the annular space to be filled. By means of paddles worked by a handle the mixture is kept stirred, and is prevented from setting.

In Mr Bartlett's paper a useful Table (p. 158) is given, showing the force required to drive a shield.

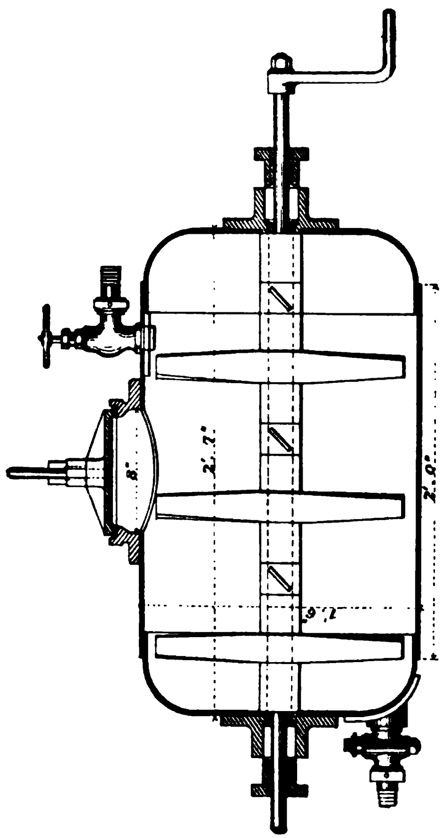
The Glasgow Harbour Tunnel, which was completed in 1895, affords a good example of the employment of the shield. There were three tunnels connected to shafts on the north and south sides of the river. These shafts were, for the most part,

16 feet in internal diameter. The two outer ones are used for



CROSS SECTION.

Fig. 61.



LONGITUDINAL SECTION.

Fig. 60.

vehicular traffic, and are level from shaft to shaft, with elevators

(described elsewhere) to raise the vehicles to the surface on either side. The centre tunnel, for foot passengers, is constructed with a gradient of 1 in 3 from the shafts, and with stairs in them, which obviates the necessity for elevators.

The tunnels were constructed in boulder clay from the south shaft about a third of the distance across the river. An interesting description of the various operations in connection with these works was published in *Engineering* on the com-

Diameter of Shield.		Circumference of Shield.	Number of Rams.	Diameter of Rams.	Pressure per Square Inch.	Forward Pressure.	Back Pressure.	Total Pressure.	Pressure per Foot Run of Cutting Edge.	Remarks.
Feet.	Inches.	Feet.		Inches.	Lbs.	Tons.	Tons.	Tons.	Tons.	
13	5½	42·3	8	7	2,240	307·8	...	307·8	7·3	Maximum obtainable.
,,	,,	,,	6	7	1,680	173·1	...	173·1	4·1	Piles used.
,,	,,	,,	8	7	1,800	247·4	...	247·4	5·8	,, ,,
22	10	71·75	22	7	2,240	847·0	...	847·0	11·8	Maximum obtainable.
,,	,,	,,	15	7	1,176	303·0	91·8	211·2	2·9	No piles used.
,,	,,	,,	16	7	1,170	321·6	91·8	229·8	3·1	Piles used.
,,	,,	,,	18	7	1,150	356·4	91·8	264·6	3·7	
,,	,,	,,	19	7	1,100	359·1	91·8	267·3	3·7	
,,	,,	,,	19	7	1,145	374·3	91·8	282·5	3·9	
,,	,,	,,	20	7	1,000	344·0	91·8	252·2	3·5	
,,	,,	,,	20	7	1,160	400·0	91·8	308·2	4·3	

pletion of the tunnels, and the following information is derived from that source.

The shield which was adopted for the construction of the tunnels is a modification of the one first used, being somewhat strengthened, although there were no indications during the carrying out of the works that this was other than precautionary.

The outer shell was 17 feet 3 inches and measured 8 feet 6 inches from cutting edge to back. The cutting edge had a

stiffening ring on the diaphragm. There were two sliding doors 6 feet by 4 feet 2 inches, but it was at no time found necessary to close the doors. Inside the diaphragm there was at the top and bottom a girder for stiffening the shield. On the platform there were two hand pumps for working a series of thirteen small hydraulic rams, 7 inches in diameter with a stroke of 2 feet. Immediately behind the diaphragm was a series of cast-iron segments abutting against each other and forming a complete circle. The hydraulic cylinders were bolted to these and through the skin plating of the shield. For grouting behind the tunnel plates there was a grouting pan about 2 feet 6 inches by 18 inches. From this pan there was a hose-pipe with an iron end-piece and nozzle. The grouting was done under a pressure of 50 lbs. to the square inch. Both shields were made by Messrs Markham & Co., Chesterfield.

HYDRAULIC BRAKE.

A brake or buffer can be made by enclosing a volume of water in a cylinder that is provided either with a perforated piston or with a small pipe connecting each end of the cylinder, which admits the passage of water slowly from one end to the other. Such an appliance admits of wide application in arrangements of machinery where the absorption of suddenly arrested energy is required. In working the starting and reversing gear of marine-engines, the piston-rod of the steam cylinder is continued and forms the piston-rod of a hydraulic brake cylinder, the ends of which are connected by a small pipe through which the fluid is pressed backwards and forwards. When the piston begins to move, the resistance of the brake is at a minimum, increasing with the motion of the piston (as the square of the speed) till a maximum is reached, which is adjusted by means of a cock.

Mr Alfred A. Langley devised a "hydraulic buffer stop"

for the purpose of preventing accidents due to trains over-running terminal stations, or dead ends, on railways, and arising either from the failure of the brakes, defects in the machinery, or carelessness in not reducing speed. A description of this was given to the Institution of Mechanical Engineers in 1886.

The principle on which it is based is the application of hydraulic resistance by the use of a piston working in a horizontal cylinder filled with water, and fixed in line with the buffers of the rolling stock. Plate 52 illustrates this appliance. Figs. 1 and 2 show a sectional elevation and plan of the general working arrangements. The piston-rod A working in the cylinder B is of solid steel, 3¾ inches in diameter, and 13 feet 1 inch long over all. Upon its extremity is fixed a buffer head, similar to those of the rolling stock. In its normal position (ready to receive a train) it projects 6 feet from the face of the cylinder, allowing 2 feet for the construction of a fixed stop, as shown at L. This consists of four permanent-way rails placed transversely across the front end of the cylinders, two over and two under the piston-rod, and connected together by a loose girder through which the rod passes. The cylinder B is shown in sectional plan by fig. 5. It is 4 feet 7½ inches long, cast with a flange on each end, and bored out to 12 inches diameter, with 2½ inches thickness of metal. Covers are bolted to both flanges, and are fitted with hydraulic glands, with cup leather packing, for the piston-rod, which passes through both ends of the cylinder. An india-rubber ring 1 inch thick is fixed round the rod on each side of the piston, to form a cushion between the piston and the cylinder ends, the piston being turned to an easy fit. The constant circumferential clearance between the cylinder and the piston is 0·38 of a square inch. In addition to this constant space, a gradually diminishing area of passage has been contrived, whereby a uniform resistance is maintained throughout the stroke. This is accomplished by a wrought-iron strip C, 3 inches wide, fastened by stud-

HYDRAULIC BRAKE.

PLATE .52.

Fig: 1.

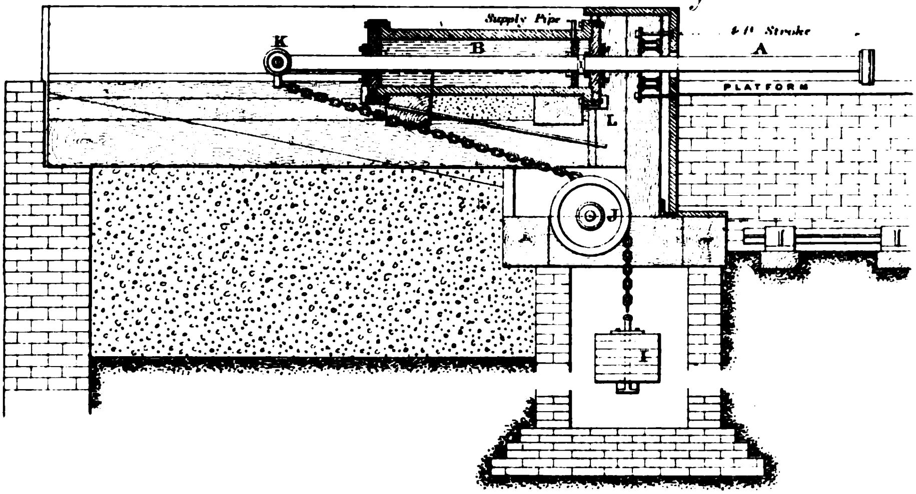


Fig: 2.

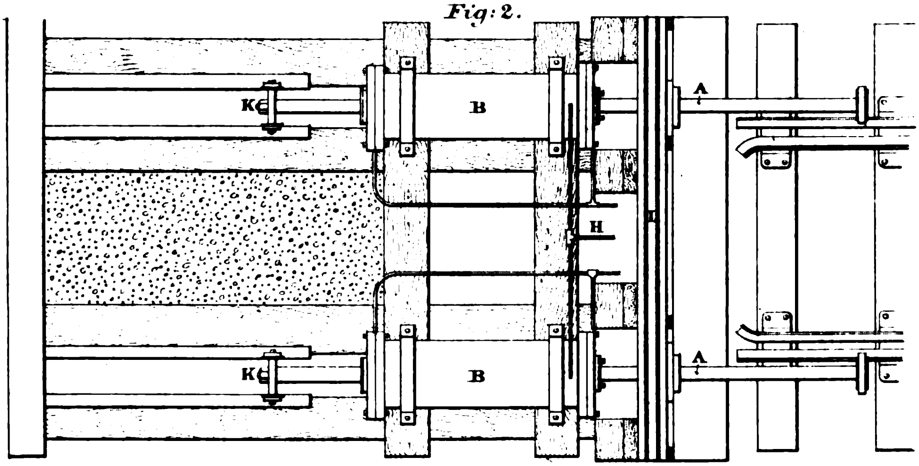


Fig: 3.

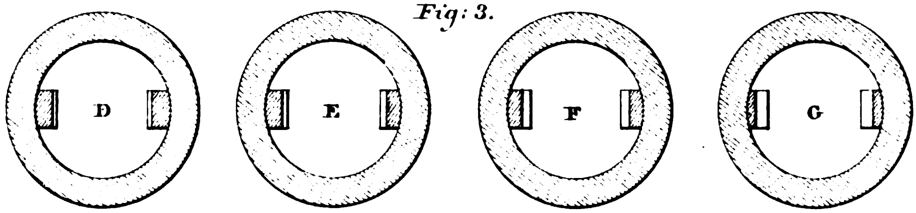


Fig: 4.

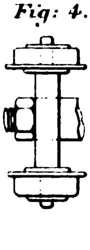
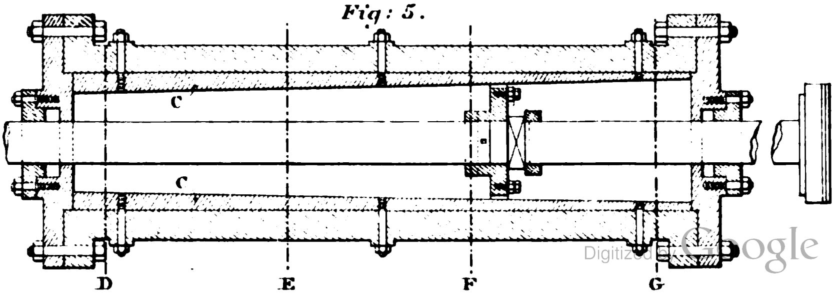


Fig: 5.



Tho.s Kell & Son Lith

screws along each inner side of the cylinder. They project $\frac{9}{16}$ of an inch into the cylinder at the commencement of the stroke, and taper up to $1\frac{1}{16}$ inch at the rear end. This wrought-iron strip fits into a corresponding slot $1\frac{1}{16}$ inch deep, which is cut out in each side of the piston.

When an impact takes place, the piston is forced backwards. The clear space between the tapering strips and the slots in the piston becomes less and less, as shown by the diminishing areas of the waterway (the thin rectangular strip with the hatching) in sections G F E and D, so that, notwithstanding the diminishing speed, an equal amount of resistance is maintained until the train is at rest. The waterway of G is 4·96 square inches, of F is 3·18 square inches, of E is 1·40 square inch, and of D is 0·08 of a square inch. By means of adjusting screws, applied to gauge plates, the proper sizes of the openings through the pistons were determined by experiment. The cylinder is kept constantly filled with water by a supply pipe H fixed to the front of it. When released, the piston is drawn forward again into its original position by the action of a counterweight I, suspended in a pit under the forepart of the buffer by a $\frac{3}{4}$-inch chain, which passes over a fixed pulley J under the cylinder, and is attached to a crosshead K upon the back end of the piston-rod. This crosshead has a wheel on each side (as shown in detail in fig. 4) running along a guide path. The counterweight is composed of cast-iron discs, with a packing of felt between each, and a packing of india-rubber between the bottom weight and the holding bolt, to take the first strain upon the chain, when the buffer is struck. Each buffer is designed to work separately, in order to avoid the unequal compression which might occur if two were connected by a cross-head.

It has been found by experiment that a train having a speed of at least eight miles an hour is brought to a stand with less than a 4-feet stroke. The theory of the action of the stop is considered to be, that its resistance varies as the square of the velocity of the train, while the momentum of the train also

varies as the square of its velocity, so that the piston-rods will be forced back, on impact taking place, through the same actual stroke (approximately), whatever be the velocity.

HYDRAULIC POWER APPLIED TO GUNNERY.

The revolution which was brought about in the construction and working of guns when breech-loading was adopted for muzzle-loading, and when cordite was substituted for gunpowder, has been recorded in the papers of Lord Armstrong and Mr Vavasseur at the Institution of Naval Architects in 1887, and by Sir Andrew Noble at the same institution in 1899. Messrs E. W. Lloyd and A. G. Handcock (formerly in the Royal Navy and in the Royal Artillery respectively, and now connected with Elswick) published in 1893 an instructive and interesting book on *Gunnery*. From the foregoing sources much of the following information is obtained. In referring to this subject the name of Mr G. W. Rendel will always be identified.

The greater weight of the guns, and the increased rapidity with which they could be fired, called for the introduction of appliances capable of utilising these advantages which hand power could not possibly accomplish. Sir W. G. Armstrong, Whitworth & Company (as the Elswick firm is now called) have brought to a high state of perfection, both in regard to design and manufacture, the hydraulic apparatus which is now indispensable for working guns, either afloat or ashore. It will be only possible to refer to this matter briefly, although the subject is one of great importance and interest.

There is now no navy of importance in which the large guns are not worked by hydraulic power. The advantages of the system may be summarised as follows:—

(1) Hydraulic pipes can be "led" all over a ship without causing heat.

(2) If a pipe is damaged, no explosion can take place, and it is easy to discover where the damage exists.

(3) Hydraulic machines can be applied directly, as elevating presses, lifts, etc., without the interposition of gearing, and they work in perfect silence.

(4) The non-elasticity of water is of particular convenience in the application of hydraulic machinery to gun-mountings.

(5) The hydraulic system lends itself, in a way impossible with steam, air, or electricity, to arrangements for combining recoil presses with means for running the guns in and out.

DISAPPEARING GUNS.

In 1864 Colonel Moncrieff utilised the energy of recoil to bring the gun down into a protected position behind an earthwork, at the same time storing up energy to raise it again into the firing position by a "hydro-pneumatic" disappearing mounting, the principle of which is as follows:—When the gun is in the firing position, it is kept up by the liquid being at sufficient pressure to force out the ram of the recoil press. This pressure is obtained by compressed air, contained in a separate compartment, but acting directly on the liquid. When the gun is fired, the liquid is forced through recoil valves; then, instead of passing into an exhaust chamber, as is usually the case, it passes into the compressed air chamber and further compresses the air. This latter action only helps to absorb the recoil to a slight degree, the principal recoil-absorbing action being the usual one of forcing liquid through the small apertures provided by the valves. A mixture of glycerine and water has been found to be the best liquid for hydro-pneumatic mountings, as compared with water or oil. If water is used the interior of the press and air chamber would rust.

When the energy of recoil is absorbed, the gun ought to have descended into the loading position. The air will be highly

compressed, but it cannot force the liquid back into the recoil press, because the recoil valves are "non-return." A pump is always provided by which the liquid can be pumped from the recoil press into the air compartment, and the gun can thus be brought down without firing; or, if the recoil fails to bring it down sufficiently, it is only necessary to give a few strokes to the pump. The gun is loaded in the down position, and then "laid" for the object, sights being used for training, and means being provided by which the elevating gear can be set so as to give any desired elevation to the gun when it is up in the firing position. When all is in readiness a valve is opened and the liquid is allowed to pass from the air compartment to the recoil cylinder; the ram is therefore forced out and the gun rises. As it approaches the firing position, the gun automatically closes the inlet valve, and comes to rest gently. The gun having been previously laid, it can be fired directly it is up, so that it should only be above the pit for a few seconds.

After many systems had been experimented with, the hydraulic recoil press on Mr Vavasseur's plan was adopted for the English services, and nearly all over the world. Oil is used in the presses; that which comes from Rangoon best fulfils the required conditions. Fig. 62 represents the Vavasseur recoil buffers as originally fitted to 6-inch gun mountings. F F^1 are the pistons; G G^1 the piston-rods, of which one, G^1, is fixed to the rear, and the other, G, to the front of the lower carriage. H H are the rifled grooves into which fit the studs J J on the rotatory valves K K. The figure shows the arrangement in the firing position. When the gun recoils, the oil in both cylinders has to pass from one side to the other of the pistons; but as the piston-rod G^1 enters its cylinder, and the piston-rod G leaves it, some of the oil in the left-hand cylinder L^1 must pass over to the right-hand cylinder L, so that both cylinders may continue to be entirely filled with piston-rod and oil. The passage of the oil takes place through the connecting-pipe M; past the non-return valve, which it forces open against the spring; through the passage O; and into the cylinder L.

If the by-pass valve P (fig. 63) is open, in order that the gun may run out again after recoil, a certain amount of the liquid will pass through it when going from one cylinder to the other. During recoil, the valve K gradually closes the orifices Q Q through which the oil has to pass, the shape of the valve being calculated with a view to obtaining a uniform velocity of liquid. When the gun is in, it will run out again automatically, if the by-pass valve P is opened, for there would then be a passage for the liquid through the hole R. But if the by-pass is closed, the liquid is locked up in the cylinder L, for it cannot re-pass the large valve M; the piston-rod G cannot therefore

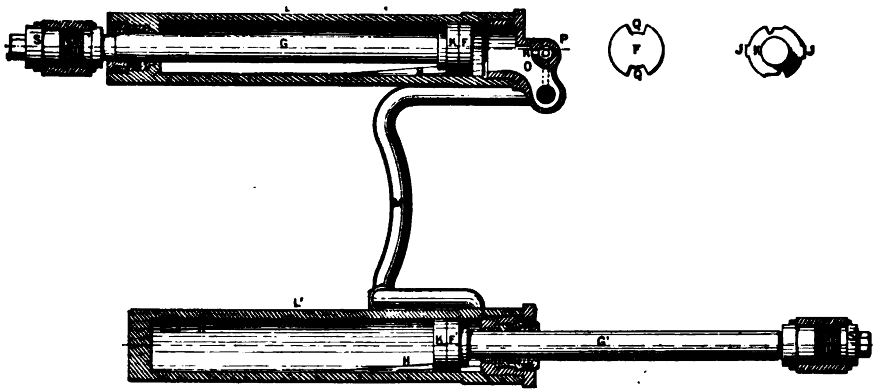


Fig. 62.

enter its cylinder. Again, if the gun is running out, it can at any moment be checked by shutting, or controlled more or less by opening, the by-pass valve.

In connecting the piston-rods to the slide brackets, the nut S should not be screwed tight up, but should be left slightly slacked back. This allows a little play, and relieves the piston rods from strains.

Fig. 64 represents the recoil press of a quick-firing gun, fitted with valve key and controlling ram. It is on the tension principle, T being the piston, and U the valve key. The piston rod is attached to the horn θ on the gun, and the same rule as given above in connection with the piston-rod nuts of Vavasseur

carriages applies here. The recoil cylinder X is generally made of forged steel, and, to save space, is screwed into a bracket Y, forming part of the cradle. V is the controlling ram, Z the small radial hole to admit the liquid into the cavity in the piston rod during recoil, W is the plug for adjusting the action of the controlling ram, and β is the bronze ring dovetailed into the steel piston, to prevent, or rather to avoid, seizing between the piston and cylinder.

The cleaning and loading of guns are also performed by hydraulic power, several systems having been devised for that purpose, particulars of which are given in detail in the book on *Gunnery* by Lloyd and Handcock.

The hydraulic engine, which is the source of pressure, always

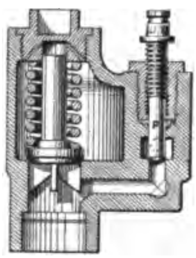


Fig. 63.

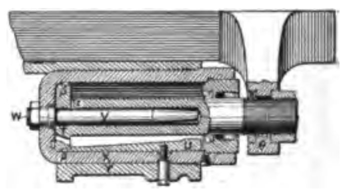


Fig. 64.

consists of a pair of engines, generally compound, arranged in tandem. An illustration and description are given on page 136.

For land defences, hydraulic and hydro-pneumatic gun carriages have been constructed for raising and lowering guns, so that the loading is done at a low level under the protection of a fortification, the gun being raised above the parapet to be fired.

To work the turrets of a battleship no power is better than hydraulic to meet the essentials of rapid movement, together with a slow one of great steadiness. The system of engine adopted in the British service for this purpose has never varied except in detail. Three oscillating cylinders, each with a ram, drive cranks set at 120° with each other. The slide valves of

the cylinders are worked by rods from an eccentric point in the trunnions. There is a reversing valve to each cylinder, but all three reversing valves are worked by one shaft, and this shaft is controlled by hydraulic cylinders, known as the "starting and reversing" cylinders.

JET PROPULSION.

The application of the hydraulic jet to the propulsion of vessels has been the subject of experiments of a more or less practical form, and of patents dating as far back as 1661. During recent years the system has been tested by the construction of several vessels which were propelled by hydraulic jets, with the result of producing much controversy amongst experts in naval matters. A paper by Mr Barnaby (read before the Institution of Civil Engineers in 1884) gives a description of an experiment in the construction for the Admiralty of a torpedo boat by Messrs Thorneycroft. This was fitted with a turbine propeller, and the design of this boat provided for utilising as much as possible the velocity of the feed-water. Just in front of the pumps the bottom of the vessel had a sudden jump upwards from the stern and towards the bow end. At this point the bottom is formed into a great scoop, which gently rises to the inlet of the pump, which is placed at an angle to reduce the effect produced by the change of direction of the feed-water entering. The velocity of this entering water causes it to rise in the scoop, and the vanes of the pump are adjusted to pick up the water without shock, and gradually to accelerate it to the speed of discharge. The peripheral velocity of the pump is 56 feet per second. The energy acquired by the water is utilised by discharging it through nozzles to orifices in the vessel above sea-level. These nozzles are 9 inches in diameter, formed of copper pipes bent to a radius of 18 inches, and so pivoted

that either end can be presented to the discharge orifice in the side of the vessel. The amount of water passed through the pumps in fifteen seconds is equal to the whole displacement of the boat. The water is discharged at a velocity of 37·25 feet per second (about 1 ton per second being discharged with a lift of $21\frac{1}{2}$ feet), the speed of the boat being 21·4 feet per second (or 12·65 knots per hour). Careful experiments were made by means of a thin plate $1\frac{5}{16}$ inch square, attached to the end of a lever and placed in the jet, just where it left the nozzle. The pressure on this plate was recorded by a dynamometer attached to the other end of the lever, and the lever was arranged so as to enable the plate to be shifted about, and the pressure to be recorded over the whole jet. The mean pressure was found to be nine-tenths of that in the centre. Professor Rankine's formula for the efficiency of the jet is as follows:—

$$\text{Efficiency of jet} = \frac{\dfrac{w\,v\,s}{g}}{\dfrac{w\,v\,s}{g} + \dfrac{w\,s^2}{2g} + \dfrac{f\,w\,v^2}{2g}}$$

f = ·0374;
w = weight of water discharged in lbs. per second;
v = speed of vessel in feet per second;
s = slip or acceleration imparted by the propelling apparatus;
g = 32·2 feet per second.

When the energy of the feed water is lost the waste per second may be expressed by $f\,\frac{wv^2}{2g}$; f being a multiplier whose value may range from an insensibly small fraction to unity, according to the suddenness with which the velocity of the feed is checked.

The efficiency of the jet was found to be ·71, and of the pump ·46. The efficiency of the jet and pump combined was ·33, this being the useful work of the jet divided by the effective h.-p. The total efficiency was ·25, this being the useful work in the jet divided by the indicated h.-p.

A comparison of the efficiency of a jet propeller with a screw propeller was made by Mr Barnaby as follows:—

Screw Boat Efficiencies:—Engine, ·77; screw propeller, ·65; total, ·5.

Hydraulic Boat Efficiencies:—Engine, ·77; jet propeller, ·71; pump, ·46; total, ·254.

The principle of hydraulic propulsion has been applied to lifeboats, and Mr Barnaby described one in the *Proceedings of the Institution of Civil Engineers* in 1897. The chief reasons for adopting hydraulic propulsion were that, while a paddle or screw would be much exposed to injury from floating wreckage, or from striking the bottom, an internal propeller would be in a position of great security, and the inlet to the pump, being placed amidships, is always immersed however much the boat may pitch. The lifeboat described by Mr Barnaby was built by Messrs Thorneycroft, of Chiswick, for use at the Hook of Holland. The hull was of galvanised mild steel. An engine actuates a crank on a shaft which works a turbine 2 feet 6 inches in diameter (made of gun-metal). The inlet pipe to it is of steel and the discharge pipes are of copper. The jets are controlled by handles on deck, and can be directed either ahead or astern, so that the vessel can be managed by the jets although it has a rudder (which can be triced up with buckles provided for the purpose) and steering gear. At a speed of 9 knots about a ton of water per second was discharged by the jets.

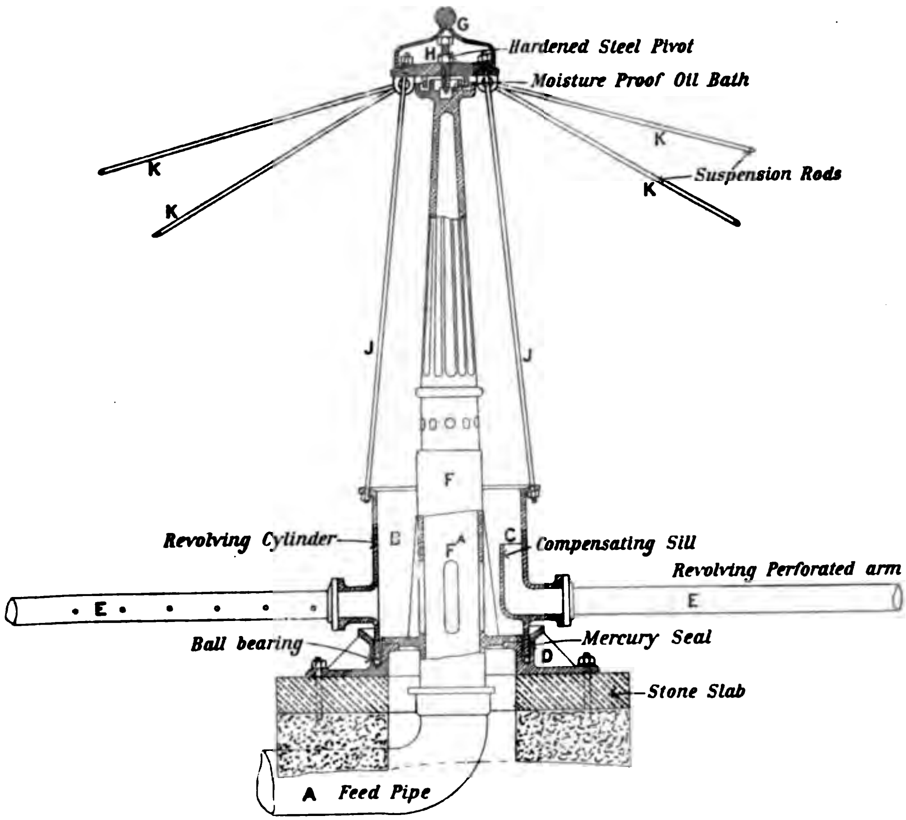
HYDRAULIC JET FOR PILE SINKING.

Mr De Burgh gives an interesting account of the use of the hydraulic jet for pile sinking in the *Proceedings of the Institution of Civil Engineers*, 1902, in connection with the construction of bridges in New South Wales. The operation of sinking was performed by forcing water through orifices cast in a shoe placed at the bottom of the pile into the strata through which

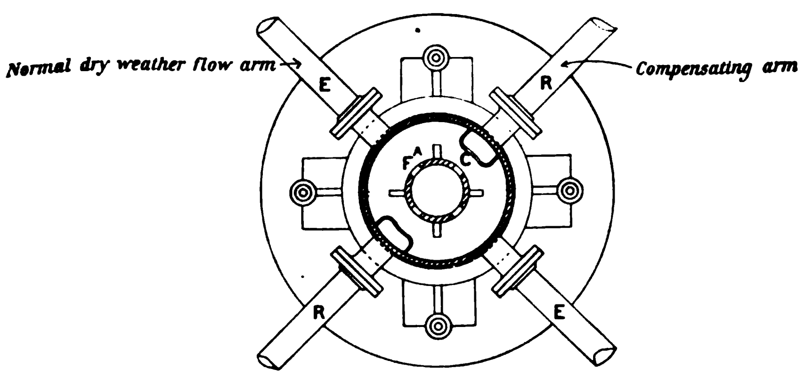
the pile was to be sunk. Experiments were made to determine the best positions for the orifices, and it was found that a central orifice of 2 inches in diameter, and 4 orifices of $\frac{1}{2}$-inch diameter, placed round, and a few inches from, the central orifice, provided the most effective arrangement in sand and soft clay. The water jet was supplied by a pump on the surface, capable of delivering 250 gallons of water per minute, at a pressure of 160 lbs. per square inch. The water was pumped into the pile itself, no internal pipe being used. Although the pump was capable of working up to a pressure of 160 lbs. per square inch, this pressure was not required, and, in fact, the pumping plant could be dispensed with where a large supply of water could be obtained at a much lower pressure. When sinking through sand the water pressure was only about 5 to 7 lbs. per square inch, but when clay was met with the pressure rose to upwards of 50 lbs. per square inch. An air lock was provided for the purpose of removing drift timber, etc., which might be encountered in sinking the piles, the compressed air for which was supplied from an air compressor in the usual way. When the air lock was being applied a man descended and cut a passage for the piles, the sinking of which was continued by the water jet.

The principle of the jet is utilised for the distribution of sewage effluents, or impure fluids, over the surface of beds composed of gravel, broken stone, clinker, or other material, through which the fluid trickles at a definite rate. Air remaining in the interstices of the material constituting the filter bed, the organic or other impurities in the fluid, are acted upon by aërobic bacteria, and purified. One arrangement is called the "Candy Sprinkler," which is shown by Plate 53. The fluid to be distributed over the bed enters by the feed pipe A, through ports F^A, passes into the revolving cylinder B, to the perforated arms E (the perforations being on one side only), and discharges from them in jets, causing the arms and cylinder to revolve, and the fluid to be sprinkled over the surface beneath. The arms E come into action at once, but the arms R receive the

Candy Sprinkler.



SECTIONAL ELEVATION.



PLAN.

fluid when it rises to the level of, and flows over, the compensating sill C. As will be seen, the arms are supported by suspension rods K, attached to a head-piece G (connected by suspension rods J to the cylinder B), which revolves on a steel pivot H, round the supporting column F. The whole rests on a base plate D having a groove for a ball-bearing sealed with mercury.

The author has designed an apparatus to automatically regulate the discharge of fluids to these sprinklers by utilising the flow to turn a small undershot wheel which works an arrangement of gearing connected with a revolving dish, in the bottom of which are outlets that come into operation at definite periods during which the fluid has a free discharge through them.

GREATHEAD'S INJECTOR HYDRANTS.

Mr Greathead perfected an appliance by which a jet of water from a high-pressure main is passed into a stream of water from a low-pressure main, which causes the stream of low-pressure water to be carried to a greatly increased height. If the lines of motion of the two currents were identically the same, so that no loss was sustained from eddies, the force communicated to the mass of water at the low velocity would represent exactly that which the high-pressure water had lost.

Plate 54 shows one of the Greathead "Injector Hydrants" as applied at the Royal Albert Docks, London.

Many experiments have been made to ascertain the quantity of high-pressure water that would be required to produce jets of water at various low pressures. The following table is deduced from experiments with a low-pressure supply from 10 to 20 lbs. per square inch, and with a high-pressure of 700 lbs. per square inch. The quantity given in the table is for a jet of 150 gallons (delivered through a 1-inch nozzle) variously estimated to ascend to a height of from 75 feet to

·84 feet, and requiring a pressure of 100 feet head at the back of the nozzle. The length of hose is taken at 200 feet of 2½-inch brigade hose, the resistance of which, for that discharge, is taken at 3 inches of head per foot of hose.

Quantity of High-Pressure or Power Water required for Various Heads of Low-Pressure Supply to produce the jet described.

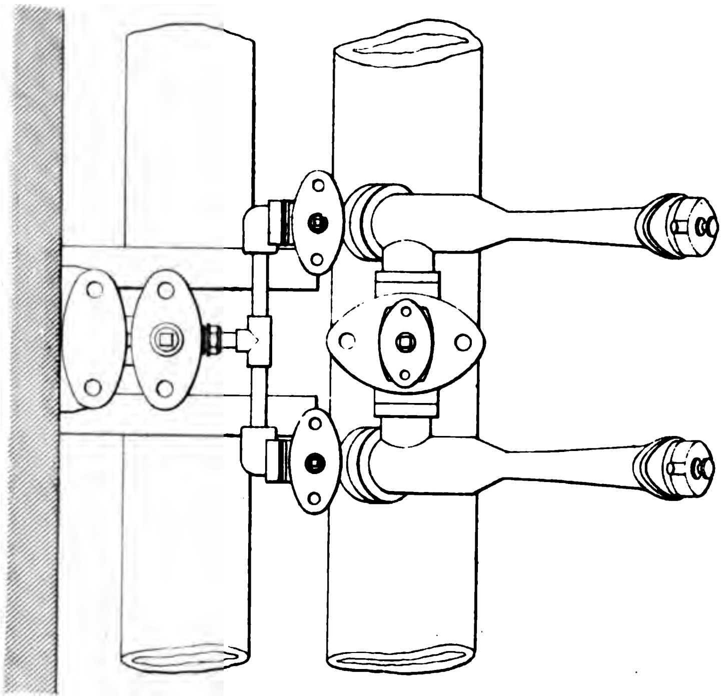
Low-Pressure Supply.		High-Pressure at 700 lbs. per square inch.
Lbs. per square inch.	Feet head.	Gallons per minute.
60	138	3·7
50	115	10·9
40	92	18·1
30	69	25·2
20	46	32·4
10	23	39·6

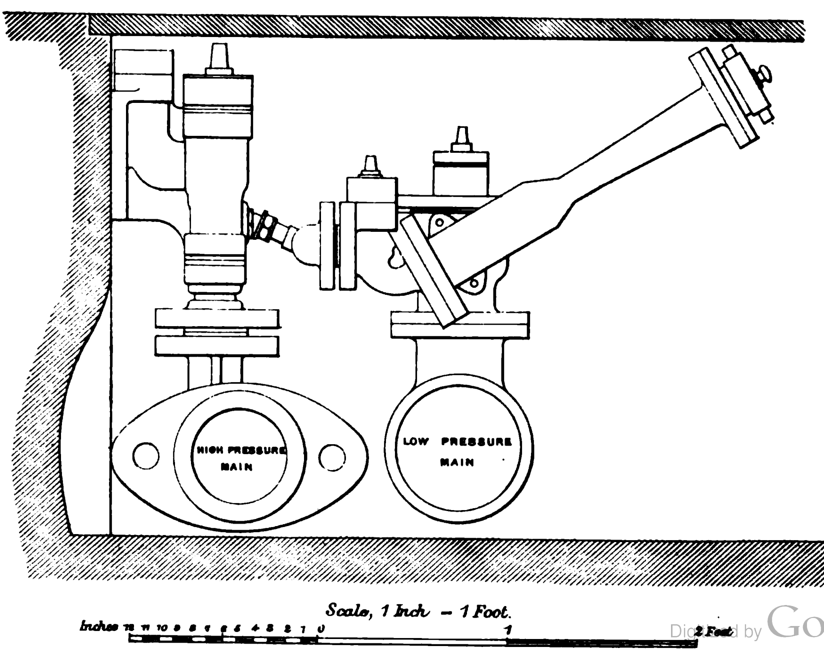
Mr Greathead advocated the application of these hydrants by the public bodies for the extinction of fire. It is well known that the pressure in the mains is not, except in isolated cases, sufficient for giving powerful jets of water without the intervention of fire engines. He proposed that injector hydrants should be placed under the footways, and be connected with the constantly charged mains of the water companies, and with a high-pressure supply pipe deriving its water from accumulators and pumps driven by gas or other engines placed at the fire brigade or police stations. Upon a hydrant being used, the nearest accumulator would fill and start the engine and pumps automatically in the ordinary way, and thus, in the case of a large fire, involving the use of a number of jets, several stationary engines would come into operation. The power would thus be available on the occurrence of a fire exactly where and when it was required.

Up to the present time the hydrants have only been adopted in London by private persons for the protection of themselves and their property, though in Hull the Corporation have put them down in parts of the city.

Another application of the injector hydrant is for drainage

INJECTOR HYDRANT.





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purposes. The iron tunnels, for instance, of the City and South London Railway were kept free from the condensed vapour which collected in the inverts of the tunnels in considerable quantities in certain conditions of the atmosphere. There the hydrants derived their supply of high-pressure water from the hydraulic mains from which the lifts at the stations were worked, and which ran through the tunnels. Their merits for this and similar purposes were that they occupy very little space and cannot get out of order, having no working parts. Those on the City and South London Railway went into a space of not more than 12 inches long and about 3 inches in diameter, and with a high-pressure nozzle of about $\frac{1}{16}$-inch gave a discharge of about 100 gallons per minute through a 2-inch pipe to and up the nearest shaft into the street drains.

The Hydraulic Engineering Company have a neat arrangement of hydraulic ejector which has been specially designed for draining basements and other low-lying floors of buildings, etc., into which water is constantly or occasionally leaking, and which cannot be drained in the ordinary way by gravity. When intended for draining a basement the apparatus is preferably fixed in a pit or sumph below the floor, and into which the water drains. The apparatus is designed to be operated by pressure water from the mains of the London Hydraulic Power Co. The starting and stopping are controlled by a float which rises and falls with the level of the water in the sumph. As the higher level is approached, the apparatus comes into action, ejects the water until the lower level is reached, when the action stops and the consumption of pressure water ceases until the accumulation of fluid again brings it into action.

Several of these have been fixed in warehouses where, previously, personal attention was required more or less every day, and, in cases of heavy rains, on Sundays also. No personal attention is now needed beyond an occasional inspection at intervals of a few weeks.

BALL'S PUMP DREDGER.

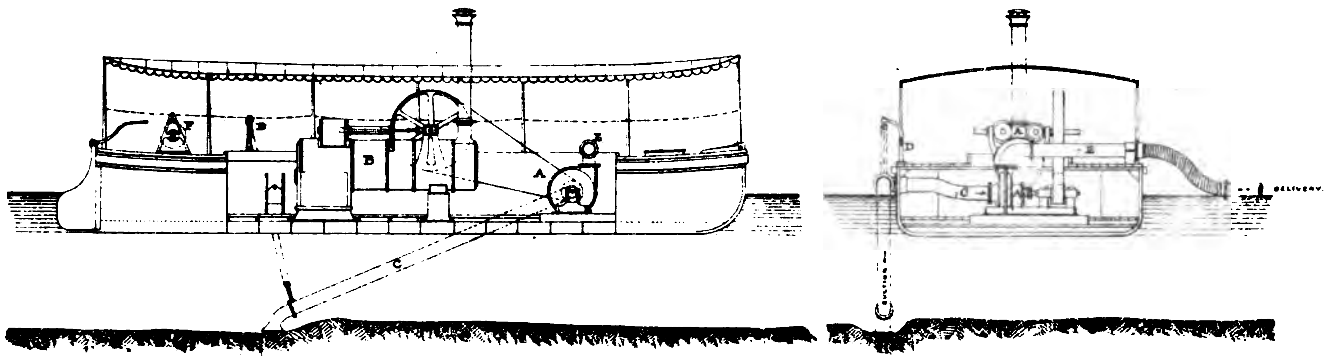
A system of dredging by pumping has been employed with success at various places. Sand and gravel passing through ordinary pumps destroy them rapidly and interfere with their working, so that the machinery is continually being stopped and under repairs, consequently dredging by pumping could previously only be employed in dealing with light mud and fine sand.

The Ball pumps are of a design distinct from that of ordinary centrifugal pumps, the aim being to allow big stones to pass without damaging the pump. Special materials and arrangements are employed in their construction to prevent the destructive wear which arises when rapidly revolving parts running against fixed parts are fed with masses of material containing sharp grit.

Plate 55 shows a general arrangement of a Ball suction dredger as is used for river and harbour work. A is a pump driven by an ordinary semi-portable engine B, and running at about 500 to 600 revolutions per minute. C is the suction pipe with a nozzle at the end, which is sometimes filled with a grating to limit the size of the stones that are to pass. The suction pipe is raised or lowered by means of a chain which is worked from a davit D. E is the delivery pipe through which the spoil is conveyed to the point of discharge. This can be carried by timber floats or by other suitable means. F is the winch which is used for hauling the vessel about while the dredger is at work.

The pumps receive the material by the centre, and it is brought into the shell of the pump by a duct in the casting which describes a spiral; so that when the stones and gravel enter the pump, their motion, which was parallel to the shaft, has been transformed into a rotary one, so that the material is already running in the same direction as the blades of the inner fan, the result being that its motion is gradually

BALL PUMP DREDGER.



West, Newman Photo

accelerated by the fan blades, and it therefore issues tangentially from the pump. The height to which the material will ascend varies with the nature of what is dredged. The large stones do not give the most trouble, the thick clayey gravels being the most difficult to deal with.

Where weeds have to be pumped, a movable valve in a Y piece or breech is employed, by which the material is sucked alternately through one arm and the other, each being supplied with a suction pipe and nozzle. As soon as one nozzle gets choked the suction is diverted to the other, and the choked one is lifted to the surface and the weeds are removed by an iron claw. Another means of removing material is by employing the pumps to deliver a high-pressure jet into the suction pipe of the dredger, by which an ascending motion of the mixture is caused, and thereby a vacuum is produced at the end of the suction pipe resting on the soil. By this, the material to be dredged is sucked into the dredging pipe and is forced up into the delivery pipe without ever passing through the machinery. This system has been used abroad with good results.

Mr Langley, the (then) Chief Engineer of the Great Eastern Railway, described in a paper that was read before the Institution of Mechanical Engineers in 1882 the employment of one of the Ball dredgers (with a 12-inch suction) which was used at Lowestoft. The amount of material dredged averaged 200 tons of sand and shingle per hour, and this was raised from 7 to 25 feet high. At Angers, on the river Maine, near its confluence with the Loire, in France, a dredger, with a suction pipe 11 inches in diameter, was used by Mr A. Pellerin to remove sand, which was effected at the rate of 106 tons per hour. The same contractor used a 9-inch dredger at Poole, in Dorsetshire, and moved 500 tons of fine sand per day from a depth of 9 to 12 feet, the material having to be deposited at a distance of five miles.

As the delivery pipe can be carried distances (by buoying or floating it, as already stated), it follows that this system of pump-dredging enables large amounts of material to be

dislodged and deposited elsewhere without being brought on board, or even seen, in a very economical manner compared with the older methods of dredging.

The amount delivered by a Ball pump varies with the nature of the material dredged. The more it approximates to sea-sand and beach the better the results; the nearer it resembles clay marl, or concreted gravels, the less are the quantities that can be moved.

The Metropolitan Dredging Company of New York have recently constructed two hydraulic suction hopper dredges for improving the East Channel. These are an improvement on the "Brancker" and "Crow" dredgers used on the Mersey. The New York dredgers are of 7000 tons displacement, 300 feet long, 52 feet 6 inches beam, 25 feet depth, and have a hopper capacity of 2800 cubic yards of material, and a speed of 10 knots an hour. The dredging machinery is placed forward, and consists of a 48-inch centrifugal pump with one central suction pipe and two discharge pipes—one to either side—worked by two horizontal tandem compound condensing engines capable of lifting 75,000 gallons a minute from a depth of 40 feet.

HYDRAULIC PILE DRIVER.

In the construction of the Alexandra Docks, Hull, Messrs Lucas & Aird employed a hydraulic hoisting machine for the purpose of driving piles. The machine thus utilised consisted of an ordinary grain hoist with the working chain-drum removed. The monkey chain was worked direct from a ram 7⅜ inches diameter and 3-feet stroke. A recessed chain sheave, with grip gear fitted to it, acted as a brake, and prevented the chain which leads to the monkey from slackening. Intermediate sheaves guided the chain from the ram to the monkey. Another sheave took the chain (after it had passed over the ordinary ram sheave), and to the shaft of it a brake

wheel was keyed, which was used to prevent the chain from slackening out in the direction of the balance weight. The monkey chain was led over the top of the pile engine in the usual manner.

Were it only required to work the monkey at a stated height, the brake appliances and the balance weight would be unnecessary, as the ram would do this with the end of the chain made fast as usual. Where, however, the height at which the monkey had to be worked varied through the level of the ground from 40 feet to 45 feet, it could not be done without some such arrangement for shortening up, or letting out, the chain. This was also required for lifting the pile from the ground for fixing.

Knuckle-jointed pipes connected the machine with the hydraulic main, and could be doubled up or extended, as the machine moved in either direction.

The action of the machine will perhaps be best shown by describing the lifting of a pile. The chain is attached to one end of a pile on the ground. The brake is applied to prevent any movement at this end of the chain. The ram is set in motion, and having a 3-feet stroke, with multiplying power 4 to 1, its pullies lift the pile about 12 feet. The grip gear is then applied to prevent the pile from lowering, as the ram recedes. The brake is then loosened, and the ram is allowed to recede, the slack chain being taken up by the balance weight which lowers. When the ram is fully back, the brake is again applied, and the pressure is turned on the ram. The grip gear is loosened, and another similar lift is taken with the pile. In driving the pile, the monkey is lifted to the required height in a similar manner to that described. The brake is then applied, and is kept constantly on, until it is desired to work the monkey at a lesser height. The ram then works the monkey at whatever stroke is required. When the monkey has to be lowered (as the pile is being driven), the grip gear is applied when the ram is back, the brake is loosened, and the ram being set in motion, lifts the balance

weight, taking the chain from this end. When a sufficient quantity of chain is obtained, the brake is again applied and the grip gear loosened. Then as the ram recedes the monkey is lowered.

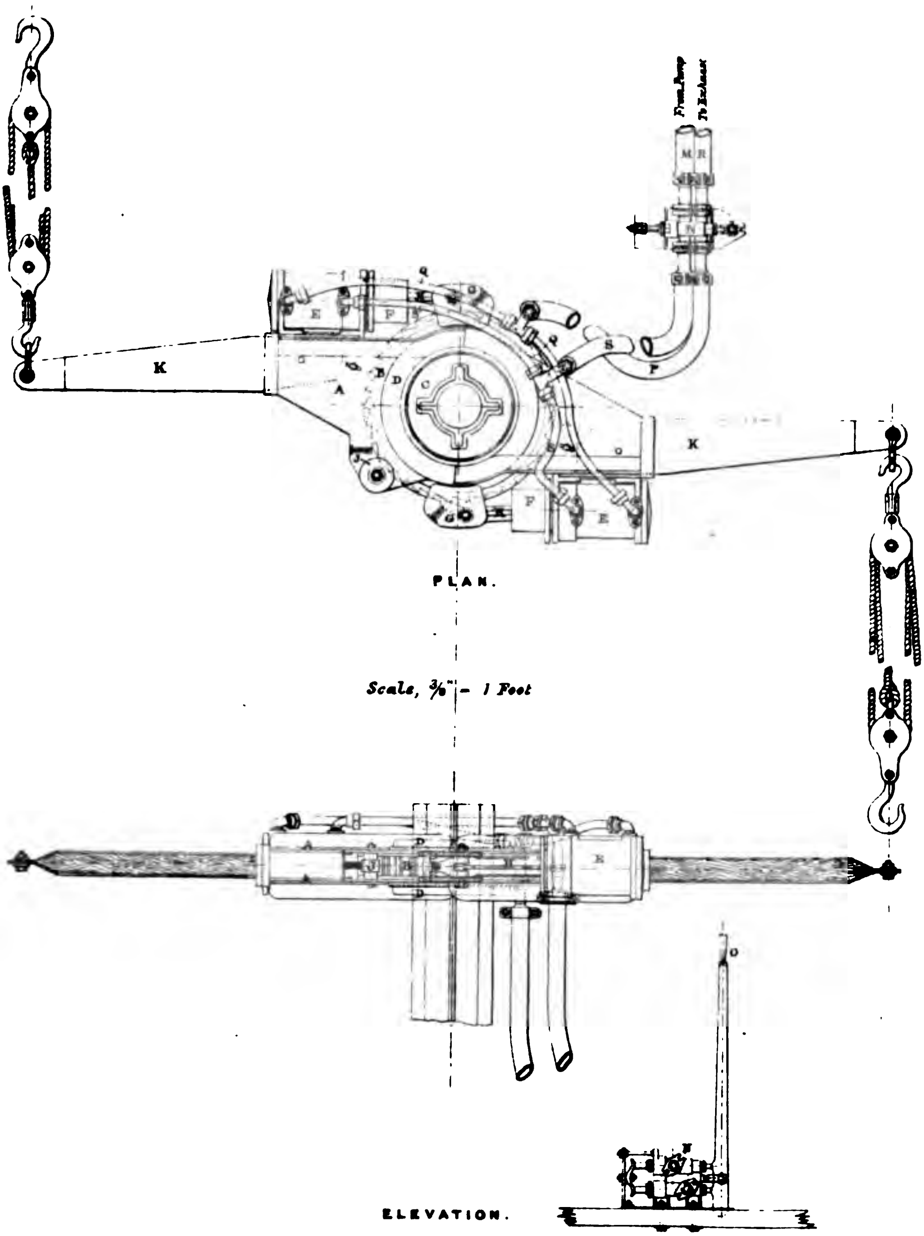
This machine was found to work very smoothly, and it fully answered the purpose for which it was employed. It gave fourteen blows per minute through an 8-feet drop, with a monkey weighing 1 ton. This rate of working compared favourably with other pile drivers which were at work at these docks, as the maximum number of blows per minute with a similar drop was only eleven.

HYDRAULIC PILE SCREWING APPARATUS.

An ingenious application of hydraulic power is that of a hydraulic pile screwing apparatus which has been patented by Messrs Wrightson & Clark, and is illustrated by Plate 56. It possesses many advantages over the ordinary capstan.

The frame of this machine consists of two wrought-iron plates marked A, between which is inserted a cast-steel ratchet wheel B, about 2 feet 7⅝ inches diameter, over the teeth, and having 32 teeth in its circumference. A boss C, cast on each side of the ratchet wheel, passes through steel angle rings D, secured to each side of the wrought-iron frame, and in which the ratchet wheel revolves. The boss C of the ratchet is cored out to suit either piles of segmental iron, or to receive the driver, which may be bolted to the top of the piles, when they are of large size and varying sections. At each side of the frame, and at opposite ends, are two hydraulic cylinders E, with trunk pistons F, which latter are connected to the ratchet and the frame G, in which the ratchet works, by a cast-steel knuckle-jointed connecting rod H. The stroke of the piston is a little more than 2 pitches of the teeth in the ratchet wheel, and therefore requires about sixteen strokes to make a revolu-

WRIGHTSON & CLARK'S HYDRAULIC SCREWING APPARATUS.



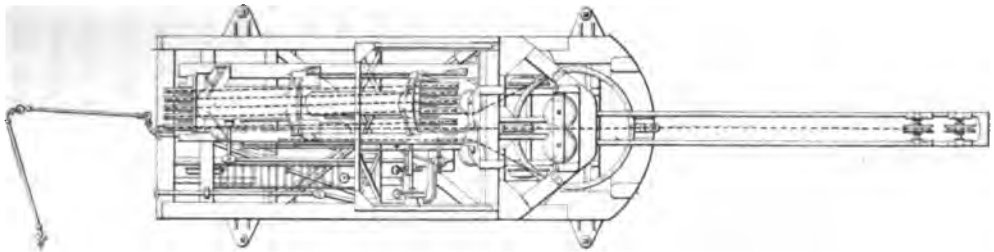
PLAN.

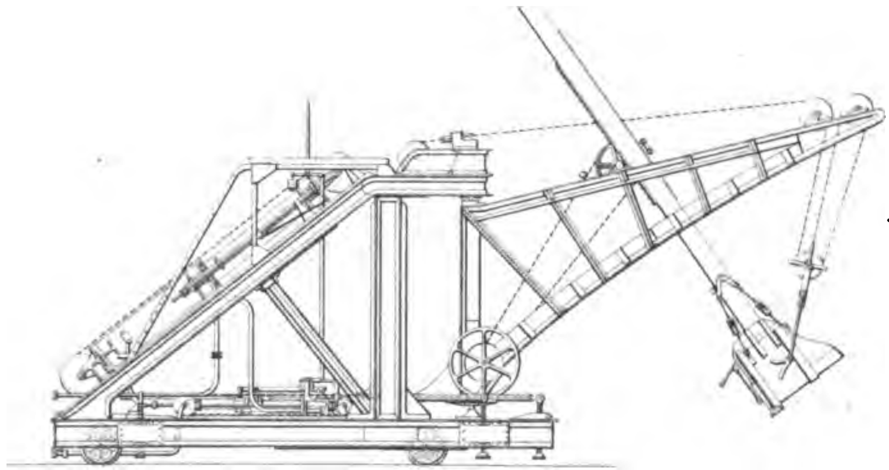
Scale, 3/8" = 1 Foot

ELEVATION.

tion of the pile. The ratchet wheel is prevented from slipping back on the return motion of the piston by a pawl J. At the extreme ends of the frame are inserted arms K, made of wood plated with iron, and at the ends of these levers are shackles to receive hooks of rope tackles, which are secured to something rigid near the apparatus, and which form the resistance to the hydraulic cylinders. The power is obtained from a set of hydraulic pumps capable of working to 600 lbs. per square inch, and having four 4-inch diameter rams 6 inches stroke. In the framing for these pumps is a small tank to receive the return water from the machine and from which the rams take their supply. The pumps are driven by a belt from a portable engine placed in any convenient position. From the pumps the water is conveyed by the wrought-iron pressure pipe M to the working valve N, which regulates the supply and the exhaust to and from the machine. The valve is actuated by the hand-lever O. The pressure is conveyed to the back end of the hydraulic cylinders by an india-rubber hose pipe P, and by copper pipes Q, by which also the discharge water is carried back to the valve and pumps by the waste water pipe R connected to the waste tank. There is also a constant pressure connection S between the working valve and the front end of each cylinder, by which the pistons receive their power for the backward stroke. But few men are required to work this machine compared with the ordinary mode of screwing by capstan head and hand winches, and piles can be screwed in much less space. The power is regularly and uniformly applied, and consequently the pile is accurately driven without any tendency to drag the pile out of position, so that, except in the case of heavy piles, very little guiding is necessary. There is no fleeting over of ropes as is usual in the case of screwing by winches of the ordinary type, so that a much more continuous motion is given to the pile, which is important, especially when screwing in sand or silty ground, whilst its action is quicker than that of a capstan driven by ordinary steam winches. It is as easily applied

HYDRAULIC EXCAVATOR.





Tho. Kell & Son, Lith.

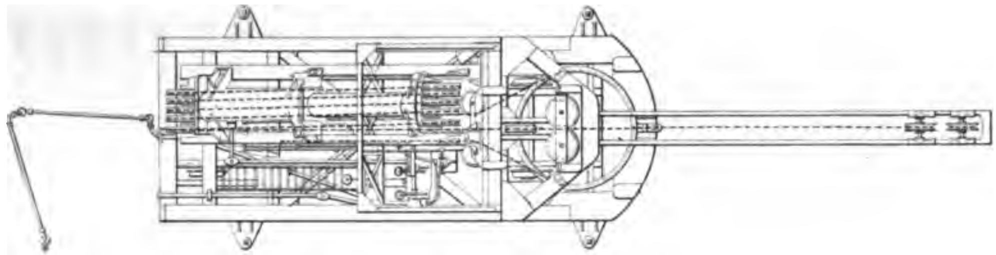
to battered as to plumb piles, and when either of these are inclined to deviate from their true line they can quickly be thrown into any other position in order that they may be worked back again to their true place.

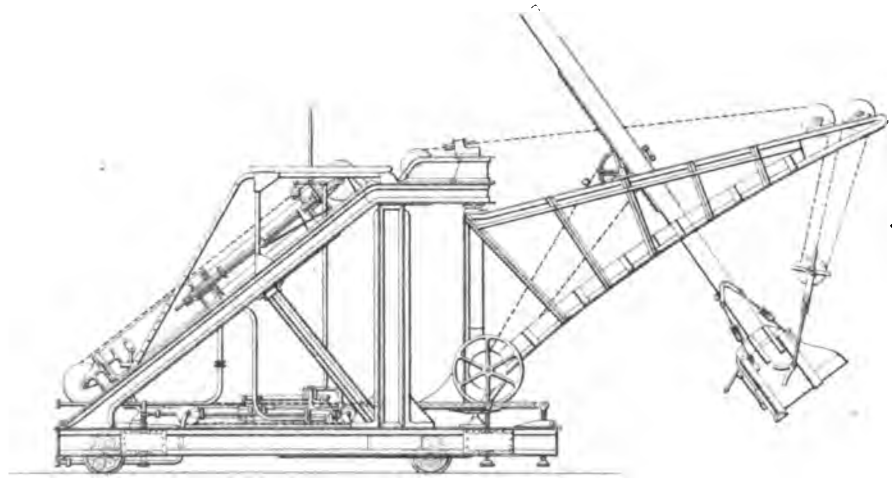
HYDRAULIC EXCAVATOR.

During the execution of the works at the Alexandra Dock, Hull, it occurred to Mr (now Sir) John Aird to excavate the material by utilising the water-pressure in the mains that were laid for working the permanent hydraulic machinery of the dock. A machine to accomplish this was accordingly constructed as shown by Plate 57. The circumstances were favourable to the utilisation of hydraulic power, inasmuch as it was within easy reach of the machines to which it had to be applied. The "hydraulic navvies" (as they were called) were, however, at times working at a distance of half a mile from the source of the power; and as there were several cranes, hoists, and other machines which abstracted power at various intermediate points, it was considered that the effective pressure at the "navvies" was about 700 lbs. per square inch, although the accumulator pressure was 750.

The machines are fitted with main rams E, 14 inches diameter and 4 feet 6 inches stroke. The chain for drawing one scoop through the excavation works over sheaves F, the multiplying power being 10 to 1. The chain at the scoop end is worked over sheaves G, twofold, thus giving a ratio of 5 to 1 in speed and stroke on the ram and bucket. The range generally required for the scoop was from 15 to 18 feet. In ordinary working about 3 feet 6 inches stroke was required on the ram. There are two smaller rams H (to slew the main jib) 4½ inches diameter and 4 feet 2 inches stroke, which are fixed horizontally on the top of the bottom framing. The chains from these are attached to opposite sides of the circular platform at the bottom of the jib.

HYDRAULIC EXCAVATOR.





Thos Kell & Son Lith.

The machines are moved backward and forward by means of a hydraulic cylinder J, 3¼ inches diameter, fitted with a piston. The piston-rod is attached to a rocking lever K, about 2 feet 6 inches long, which is centred on the leading axle. This lever is fitted with two catches, reversed, which gear into a double reversed toothed ratchet-wheel M, on the same axle L. The cylinder is arranged so that the pressure can be applied to either side of the piston; therefore, by putting either one or other of the catches into gear, the machine is moved backward or forward. The stroke of the piston is 10 inches, and the ratchet gearing is so arranged that the machines travel about 4 inches each stroke.

The machine being set to work in a cutting (say) from 15 to 18 feet deep, the scoop is drawn up by the main ram through the "face" of the excavation, taking a cut from 4 inches to 6 inches thick, which is just sufficient to fill it by the time it reaches the top. The jib is then slewed round (by the 4½-inch horizontal rams), when the scoop is brought directly over the wagons on either side. The catch which holds the door at the bottom of the scoop is then freed, and the load is discharged into the wagon. The jib is then slewed the reverse way, and the scoop is lowered, by exhausting the water in the main cylinder. The scoop weighs about 25 cwt., and has a capacity of 1½ cubic yards, making a total dead load of about 3¼ tons, independent of the resistance due to the scoop cutting through the material.

The hydraulic pipes close to the machine were in 9-feet lengths, fitted with knuckle joints, which admitted of their being so connected to the main pipes that they could be doubled up at starting, and could be extended as the machine advanced for a distance of about 18 feet, before additional pipes were required for the main. When this distance had been reached, the knuckle-jointed lengths were again brought forward and doubled up.

The greatest quantity of material that one of these machines excavated in a day was about 750 cubic yards. The circum-

stances, however, under which they were worked were far from favourable, as the material was of a soft slimy nature, and caused difficulty and loss of time in keeping the machines in a level position. Under more favourable circumstances, these machines were considered to be capable of excavating 1000 cube yards per day each.

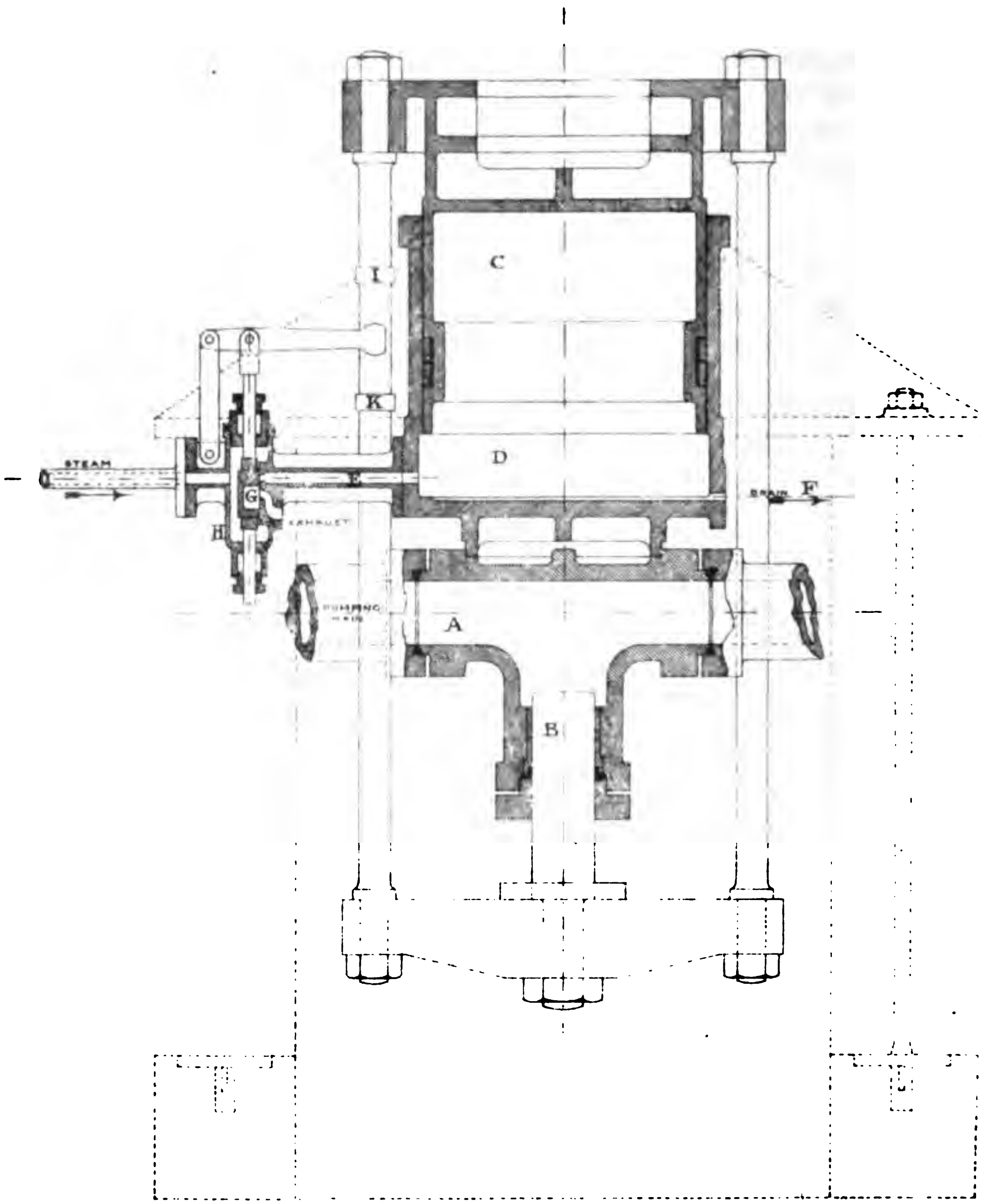
It was found that the "hydraulic navvy" had an advantage over the "steam navvy" owing to there being fewer wearing parts. The action of the working parts was also much smoother, by which the vibration was reduced, and fewer repairs were necessary. A saving resulted, not only in the cost of repairs, but also in the time for doing them.

SCHÖNHEYDER'S PRESSURE REGULATOR.

In connection with pumping machinery generally, but more especially with that of the rotative class, it is necessary to provide an equalising vessel, the function of which is to receive the excess of water delivered by the pump (above the mean flow) at certain periods of a revolution, and to supply to the main at other periods the deficiency (below the mean flow), so as to ensure a nearly uniform speed of water in the pumping main. Pumps of the "Duplex" and the "Three Throw" type have a fairly uniform rate of delivery, but when forcing into long mains it is usually considered necessary to provide even these with air-vessels. When, however, the pressures are very high, these cannot be used, as the air becomes absorbed by the water, and loaded plungers, springs, etc., have been employed as substitutes, but they are all deficient in power of regulating themselves according to the varying pressures in the main. The automatic pressure regulator of Mr W. Schönheyder is designed to meet this, and an illustration is given on Plate 58.

A is the pumping main through which the water flows from the pumping engine. B is a plunger, working freely through

SCHÖNHEYDER'S PRESSURE REGULATOR.



West, Newman. Photo

a leather or other packing. C is a plunger or piston connected to B, and working freely, but steam-tight, in the cylinder D. E is the steam admission passage, and F the drain which is furnished with a suitable regulating valve (not shown). G is a slide valve working in casing H, and in connection with these are the ports and passages. The valve G can be moved up or down by a rod and lever from the stops I and K, secured to one of the side rods. Steam is supplied to casing H; the drain is kept slightly open for discharge of condensed steam, and the working of the apparatus is as follows:—When the flow of water from the pump is below the mean, the plunger B will (by the action of the steam in cylinder D) be pressed inwards to supply the deficiency, and when the flow is in excess it will be forced outwards, slightly compressing the steam in D. Should the steam pressure in D be insufficient to balance the water pressure, the plunger B will be gradually forced out at each movement until the stop I comes in contact with the lever, thus forcing down the valve G and admitting more steam to the cylinder. Conversely, when the steam pressure in D is too high, B will be forced inwards, and the stop K will cause the valve G to be raised a little, thereby exhausting some of the surplus steam. It will be seen that the regulator is self-acting, and it has the further advantage over the ordinary air-vessel that it does not require to be "charged"; for, from the moment that steam has been turned on to it, it is ready for work, and commences its regulating action directly the pump begins working. Air or other convenient elastic fluid may be used in place of steam. This regulator has been applied with success to several pumping installations. In one case two horizontal rotative pumping-engines delivered water through 27 miles of 4-inch main, under a total head of nearly 1000 lbs. per square inch.

DEACON'S DIFFERENTIATING WASTE-WATER METER.

This instrument measures the flow of water through a pipe and detects and localises leakage graphically. If a straight line represents no flow in a pipe, any leakage at a time when there ought to be no flow can be represented by a line parallel to this, and the flow at periods of demand at all times admits of being recorded graphically by a diagram having abscissæ for periods of time, and ordinates for flow in gallons per hour.

The instrument designed by Mr Deacon to accomplish this object is shown by fig. 65. It consists of a truncated hollow cone A A, within which is a disc B, fitting the lower and smaller end of the cone, guided vertically, and loaded to counterbalance the pressure upon its under surface in excess of that upon its upper surface, due to the flow of water upwards between it and the sides of the cone. The disc is pressed upwards by the water rising below it, until this difference of pressure is exactly equal to the counterbalance. The counterbalance being constant, the difference of pressures (or loss of head) must be constant also. It follows from this that the annular orifice between the movable disc and the fixed cone is approximately proportional to the velocity in the pipe, and to the volume flowing past the disc. The orifice being proportional also to the height of the disc above its lowest or zero position, the volume of flow is approximately proportional to that height.

When no water passes, the fact is recorded upon the diagram C, by a pencil carried by a wire attached to the disc, and when a flow occurs the pencil rises, the height to which it rises being approximately proportional at each instant to the volume passing at that instant.

The diagram is caused to revolve by clockwork at D, and is so ruled horizontally that the heights are exactly proportional

to the volumes. The actual volumes for each position of the disc in each class of meter have been very accurately ascertained by quantitative measurement.

Meters can be placed upon a system of water mains so

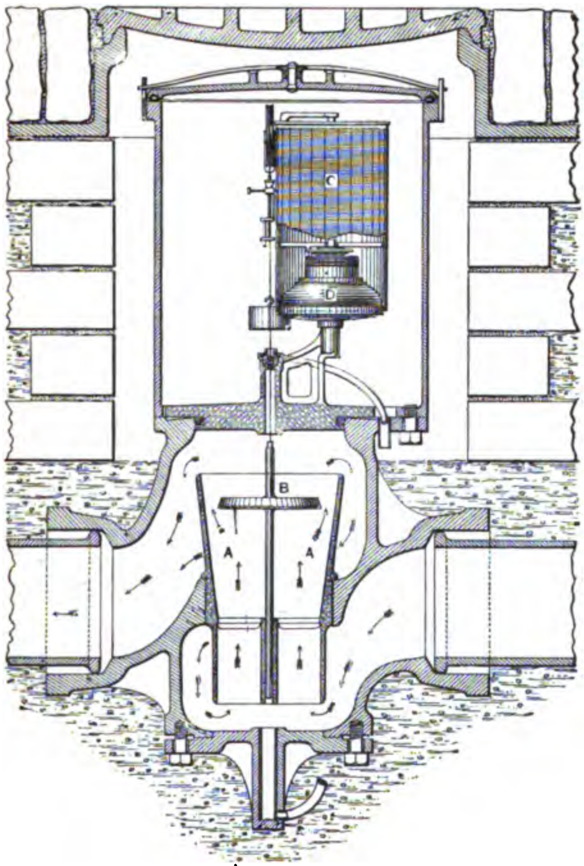


Fig. 65.

that each commands a certain district. The height of the uniform horizontal line in each meter shows the waste. An inspector visits the district where this leakage exists, at night. He listens at the stop-cocks in rotation

with a rod, used like a stethoscope. By partially closing the stop-cock, so as to contract the area of the orifice, he can increase the sound. He closes those stop-cocks at which a sound is heard, and notes the position and time. The meter records simultaneously the time of each closing; and by the difference between the volume before and after each closing, it also records the leakage that has been prevented by that closing.

Another use of the meter, termed a disc gauge, is for the purpose of measuring the flow in large mains. One such is fixed near Oswestry on a 39-inch main of the Vyrnwy aqueduct for the supply of Liverpool. This instrument has proved useful, not only for the purpose of measuring the flow of water, but also as a means of checking the walksmen along the line of aqueduct, in connection with the opening and closing of the stop-valves.

IMPERIAL POSITIVE WATER METER.

Mr Schönheyder has devised a meter (made by Messrs Beck & Co.) which deserves mention, as it is capable of measuring very small flows, and is simple in construction and in working. Fig. 66 shows the arrangement of the meter with the cover removed.

Figs. 67 and 68 show sectional views of the meter.

The lower portion A contains the three cylinders B, and the valve-seating C, with its three ports and passages D, communicating with the bottom of the cylinders. There is a discharge port and passage E, and inlet and outlet connections F and G, also the strainer H. I is the cover, with the rib K for holding down the strainer. An unequal spacing of the bolt-holes prevents the cover from being wrongly fixed to the lower portion. L is the valve with its three arms, in the ends of which are cup-shaped bushes M, for receiving the

spherically-shaped heads of the piston-rods N, and to these are secured the pistons, composed of upper and lower piston-plates O, nuts and flexible piston cups P. The water entering the meter (as shown by the arrows) passes up through the

Fig. 66.

strainer into the upper portion of the casing, and presses equally downwards on all the three pistons, and also on the valve. According to the position of the valve the lower end of each cylinder in succession is communicating with the outlet passage E, and its piston is therefore forced down by

the superior pressure above, thus discharging the contents of the cylinder. At the same time one (or both) of the other cylinders is having its piston raised, whereby water is admitted through the passages, and the lower part is filled. Thus each lower end of the three cylinders B is in due course filled and emptied, one or two pistons always supplying the active force, so that there is no dead point.

The length of the stroke is regulated by the flanged pro-

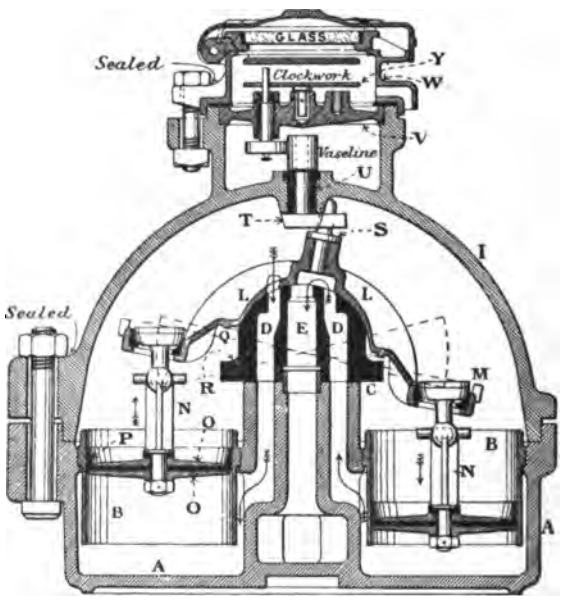


Fig. 67.

jection Q on the valve L, coming into rolling contact with a similar flanged R on the valve seating C. A slight skew of the ports causes the pistons to endeavour to take a longer stroke than they should, the roller paths restricting this tendency. The teeth in the valve and the notches in the valve-seating prevent the valve from turning round on its own axis. The valve-pin S engages the crank of the crank-spindle T, which communicates motion to the clockwork in

the usual manner. U is the bush in the cover. V is the counter-plate supporting the lay-shaft with its worms and

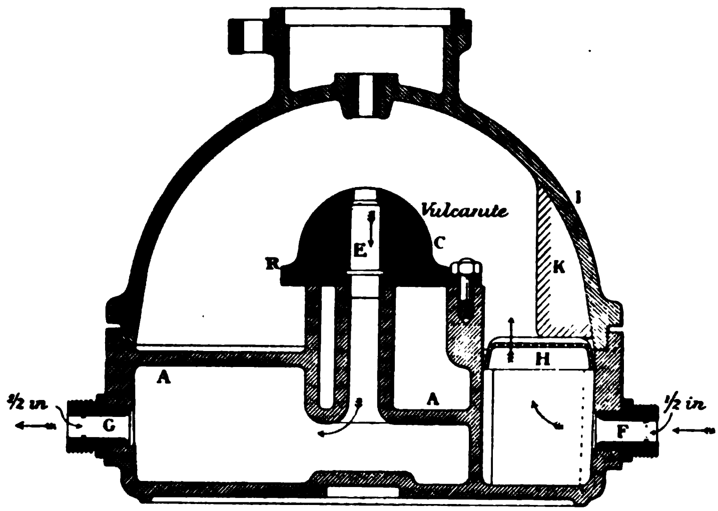


Fig. 68.

wheels. W is the dial-box protecting the clockwork, and Y is the counter.

KENT'S STANDARD WATER METER.

In measuring small flows of water, some forms of meter cannot be relied on. A recent positive meter by Mr Kent (called the "Standard") deserves notice, as the construction of it appears to meet the conditions upon which continuity of recording variable flows depends. Plate 59 gives details of the construction of this meter, which consists mainly of three parts, namely, the top, the body, and the port-block and registering gear contained between the top and body

It is a two-cylinder meter, but each cylinder is divided into an upper and a lower portion shown as 1*t* and 1*b* and 2*t* and 2*b* respectively. The passages leading to the top and

bottom of these cylinders are contained in the main casting, and connect respectively to the top and bottom faces of the port-block (3), and are controlled by means of the valve (4), which moves in an eccentric path on the face of the port-block.

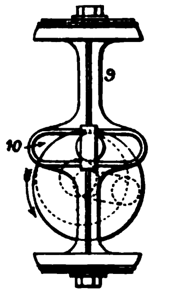
The inlet passage (5) leads into the upper portion of the body, to the whole of which it has free access. The circular outlet passage (6) connects with the boss on the under side of the port-block, communicating with the annular outlet port (6*a*).

A crank-shaft or spindle passes through the centre of the port-block, and carries at either end a crank at right angles one to the other. These cranks are fitted with crank-pins which work respectively in links (10), forming part of the frames (9), connecting the pistons belonging to the top and bottom portions of each cylinder.

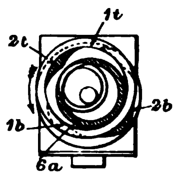
On No. 1 side the spindle is provided with an eccentric (4*a*) on which is placed the annular valve (4) which is actuated thereby. The spindle also carries the worm (7) which drives the counter-gearing.

The dial portion of the counter is placed in the counter box (8). The circular valve may be described as an annular "D" valve—that is, it is provided with an annular recess on the under side, the function of which is to put into communication one of the four half-moon parts which connect with the passages leading to the top and bottom of each cylinder, and the annular exhaust port (6*a*). At the same time as it does this, the opposite port, which communicates with the other end of the same cylinder, is fully open to the inlet pressure as shown on the sectional elevation of the valve movement and the section through port block and valve. As the crank-shaft is rotated by the movement of the pistons, the valve travels in an eccentric path, placing in turn each of the half-moon ports in communication with the proper end of the cylinder which it controls. It will be seen that as one port commences to close, the next one simultaneously commences to open, and that the ports are each

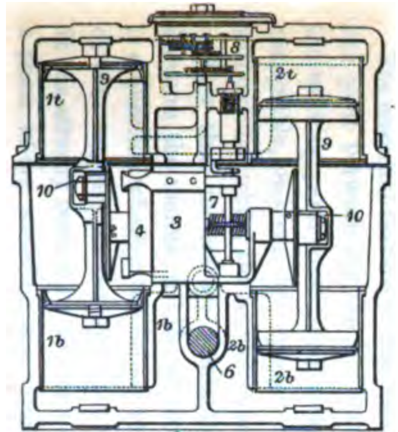
Kent's Water Meter.

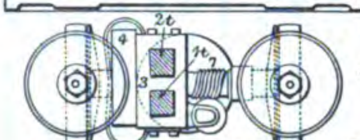


ELEVATION OF PISTON AND CRANK MOVEMENT.

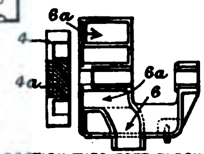


SECTIONAL ELEVATION SHOWING VALVE MOVEMENT.

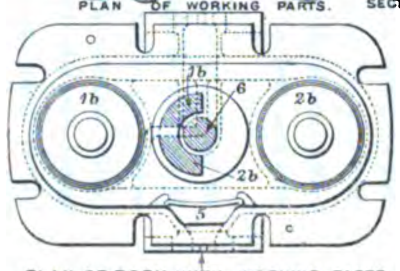




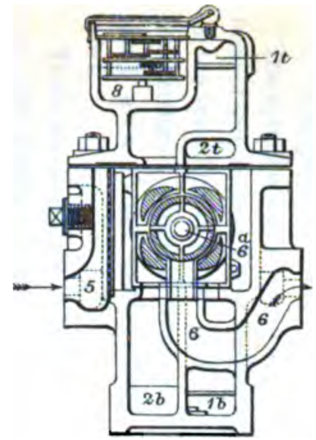
PLAN OF WORKING PARTS.



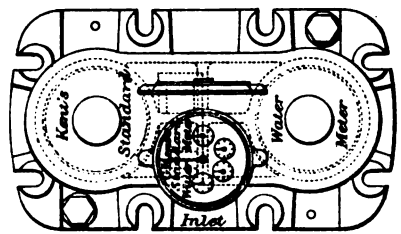
SECTION THRO PORT BLOCK & VALVE.



PLAN OF BODY WITH WORKING PARTS REMOVED.



CROSS SECTION.



PLAN OF TOP COVER.

half-way open at the half stroke. There is therefore no possibility of a "dead point."

The spindles and pins are all provided with bushes of a special form of vulcanite. These bushes may either rotate in their seats or the spindle may rotate in them. A distribution of wear is thus ensured, which prevents any part getting out of alignment, even if the meter should be in constant and heavy work.

There are no glands in the meter, the pistons and valves being the only working faces, which result in the meter retaining its accuracy. A number of ½-inch meters have been submitted to running tests under a variety of conditions with a view to demonstrate this point, and though they have passed from 500,000 to 1,400,000 gallons respectively, they have remained accurate.

The essential feature of the meter is that upon breaking the one joint between the top and bottom of the body the whole of the working parts come freely away; and as all these are interchangeable, they can be replaced by others in a few minutes without disturbing the service connections.

Now that meters are available which can be relied on to measure the merest dribble, as well as considerable volumes, it is a question whether the supply to houses will not in the course of time be charged for by meter instead of by rateable value. It has already been done to some extent, Great Malvern being a place where metering the supply has been adopted, partly because so many houses were used as private hotels and hydropathic establishments. It would be only just to private residents, who used the water only for domestic purposes, to charge for it on the actual consumption, and not on the rateable value. It will be seen, therefore, that the object sought to be obtained was not primarily to increase the revenue, but to deal with the ratepayers on an equitable basis and to effect a general economy.

THE VENTURI METER.

The depression in the hydraulic gradient that is caused by a contraction of a pipe in which liquids are flowing has been referred to in dealing with the principles which govern the flow of water through pipes. Venturi, in 1791, first observed this, and published information on this interesting discovery in 1797. A practical application of it has been made by Mr Clemens Herschel, who has devised what is termed a Venturi meter, by which the relation between the velocities and pressures of fluids when flowing through converging and diverging conduits are recorded. This meter is of great practical use, as it enables the flow of fluids to be recorded in connection with works of water-supply, irrigation, abstraction of water from rivers, compensation water to stream, and many other purposes where it is necessary to ascertain what volumes of fluid are passing through conduits at all times and under all conditions. This can be effected without requiring the introduction of apparatus in contact with the flowing fluid, and without offering any obstruction or interference with the line of flow. Fig. 69 shows a Venturi meter from a drawing furnished by Mr George Kent, the London maker.

The tube forms a part of the ordinary pipe line, and only differs from it in that it presents for a short distance a truncated reducing cone, coupled by a throat-piece to a similar expanding cone. There is therefore (as before stated) no moving part whatever in contact with the flowing water, and any interruption of the supply from such a cause is impossible. The relation of the area of the throat to that of the main in which the tube is inserted is entirely governed by the requirements of the water engineer as to maximum and minimum registrations, the proportionate area of the throat being increased when the maximum and mimimum of desired registration are high, and being decreased when they are low.

The Venturi meter is used on the Coolgardie pipe line in Western Australia. This line is 338 miles long. It is constructed

in eight sections, and on each section is placed a Venturi meter to check the work of the pumps and the integrity of the main.

The two largest meters in England are those attached to the 94½-in. mains connecting the pumping engines with the reservoirs at Staines on the Thames. These meters are capable of dealing with a quantity of 150,000,000 gallons per twenty-four hours, though this is more than they will be called upon to do. In connection with the Staines reservoirs it may be mentioned that there exists a very complete system of measurement in these works by which the water is measured at the intake from the river. It is measured on its way down the conduits to the pumping engines, from the pumping engines into the reservoirs, and on leaving the reservoirs into the distributing conduit; and again, as it is divided between the three companies interested, the quantity flowing into the system of each company is recorded. All these results are given diagrammatically to show the rate of flow, and by counter to show the total quantity passed, and they are conveyed electrically to the engine-house in order that the engineer in charge may have a complete knowledge of what is occurring over the

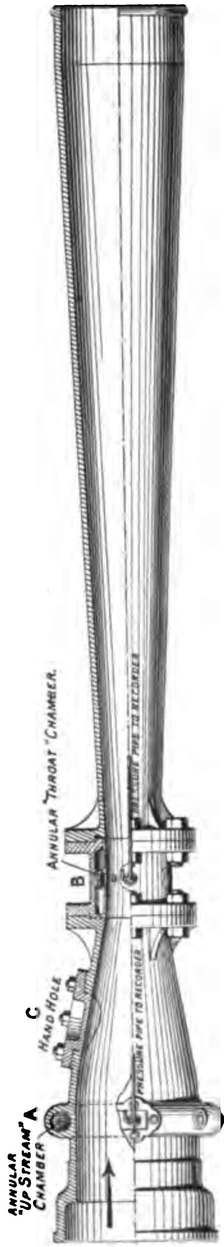


Fig. 69.

A, Up-stream annular pressure chamber; B, Throat section with gun-metal lining containing annular pressure chamber; C, Man-hole for inspecting or cleaning purposes.

whole system, the distributing basin being some eight miles from the intake.

In addition to the above results, the levels of the water in the river Thames, in the conduit, and in the reservoirs, are also recorded and electrically transmitted to the engine-house.

THE RECORDER.

This is shown by fig. 70, and consists of two parts: first, of the mercurial "U" tube shown in the diagram between the up-stream part of the tube and the recorder. This being connected with the up-stream and throat (at T on the tube) brings in the elements of "Venturi" head; and secondly, of the clockwork and gear controlled thereby, which supplies the element of time. The connection between pressure and time is established by means of floats resting on the mercury in the U tube of the recorder. The registering instrument may be fixed anywhere within 1000 feet; or if desired, the registration can be conveyed electrically to any distance.

The Venturi meter and the recorder are shown connected in fig. 70. The different pressures existing at the up-stream end, and at the throat of the meter tube, are transmitted by small pipes T U to the recorder, where they oppose one another, and are balanced by displacement of level of two columns of mercury in the cylindrical tubes, one within the other. The inner mercury column carries a float J V, the position of which is dependent on, and (as previously explained) is an indication of, the velocity of water flowing through the tube. The position assumed by an idler wheel H carried by the float, relative to an intermittently revolving integrating drum I, determines the duration of contact of

gears G and F connecting the drum and the counter, by which the flow for successive intervals is registered.

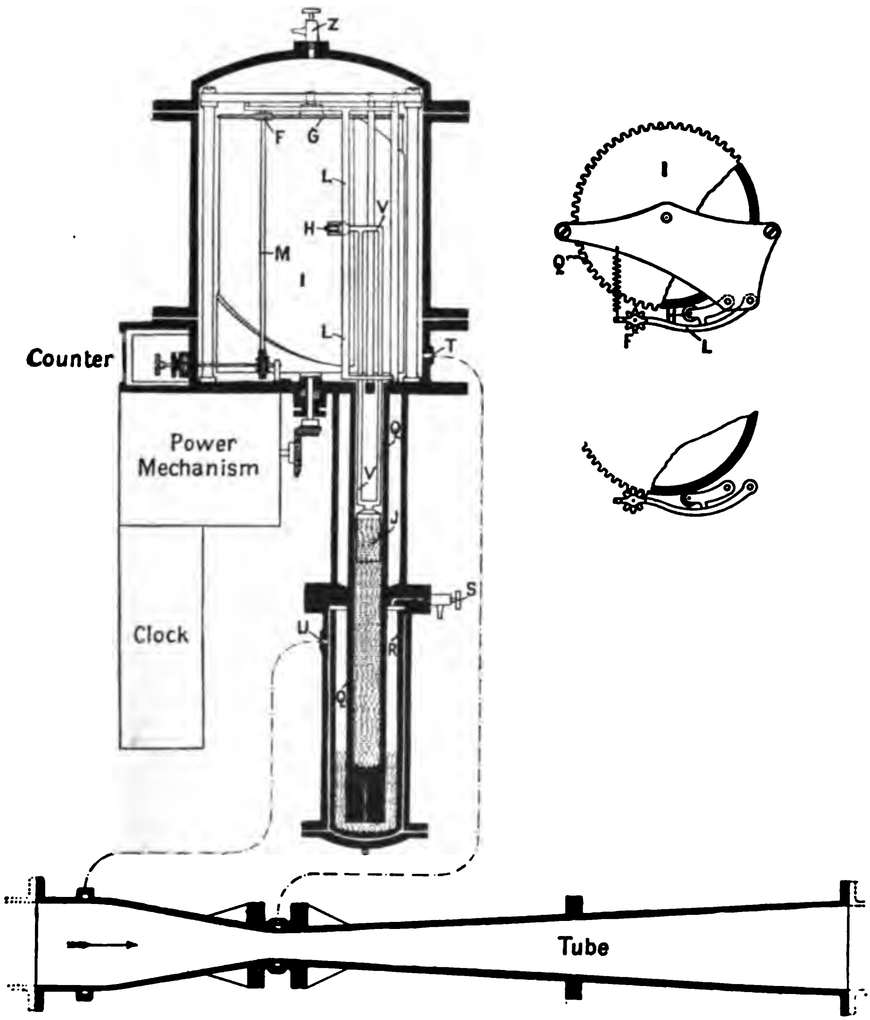


Fig. 70.

The largest meter tube that has yet been made is 9 feet in diameter, with maximum capacity of 200,000,000 gallons in twenty-four hours.

HYDRAULIC POWER APPLIED TO RAILWAY POINTS.

The working and locking of railway points and signals by hydraulic power, instead of by rigid rods and wires, has been in successful operation for years, and those of Messrs Saxby and Farmer deserve to be referred to. The fluid (a mixture of water and glycerine in cold climates) is conveyed by means of small pipes laid underground to double pistons fixed near the points, or to small single pistons attached to the signal-posts, the necessary power being generated by a pump worked by hand, steam, electricity, oil, or gas, as circumstances render necessary or convenient. The power so generated is stored up in an accumulator ready for use. By this system the working of points, however distant they may be from the station or cabin, is accomplished without any physical effort on the part of the signalman, as the little levers used for turning on the pressure can be easily moved.

Whilst points are moved to and fro with the greatest facility, means should be provided for securing them firmly in position before a train is allowed to pass over them, and for assuring the operator that such closing and locking of the points has been perfectly accomplished; and this very important object is attained by the hydraulic system in the most perfect manner. Each set of points is moved to and fro by means of two pistons, which are put in alternate communication with fluid under pressure, and with a discharge reservoir. When the fluid has moved the points by means of the pistons, it is allowed, by the opening of a valve worked by the point lock attached to the points, to pass back to the signal cabin, and by means of a small plunger fixed to the lever-locking frame, to release the signal lever, which can then be moved, and the signal worked to permit a train to advance over the points.

The movement of the point lever turns on the fluid under

pressure to the points, unlocks them, moves, and then locks them in their altered position; and, after this is accomplished, the fluid returns to the cabin and releases the levers, which can then be pulled for the purpose of working the proper signal.

HYDROMETER WITH PARACHUTES.

The low efficiency of waterwheels when the velocity of a stream and the fall are but small, has led to the substitution of an endless chain ladder with paddles to utilise the power of a stream under those conditions over a larger distance. Such an arrangement was tried on the Seine in 1865 by M. Roman, who arranged two endless chains to turn round drums supported by floating barges. To the links of these chains a series of 70 paddles were connected, each being 16½ feet long and 2 feet wide, placed 5 feet apart, this spacing giving a pressure on the rear paddles of three-fourths of the pressure that there was on the leading ones. The velocity of the Seine was 1½ feet per second, which gave an efficiency of the apparatus of 60 per cent. during the trial. A higher efficiency would be given when the velocity is increased.

Mr Yagn devised a parachute hydrometer on a similar principle, and this was described in *Le Génie Civil* in 1884. Two endless hemp cables turn round a wooden drum supported between two barges. A series of parachutes of sailcloth are placed on the cables at intervals apart of double their diameter. These parachutes open when going with the stream, being prevented from turning inside out by six small cords encircling them and attached to the cable; and they close on their return. The open parachutes, taking a slightly diverging course on leaving the drum, turn round pulleys at the end of their journeys, which are fixed in frames and kept in place by a float and weights. Deep grooves are formed for the pulleys by curved metal rods, so as to reduce the friction and the wear

of the parachutes. Experiments on the Neva at St Petersburg showed that the closed parachutes rolled easily round, and that their resistance in returning was only about 1 per cent. of the power obtained in their descent. The tension of the cables is maintained by attaching a short cable to the frame of each pulley furnished with some parachutes, and terminated by a board placed obliquely in the stream. The trials on the Neva and at Lyons show that the action of the current on all the parachutes is the same as on the foremost one, provided that the interval between them is four times their diameter, or even with an interval of two diameters if the cables are inclined 10° to the current. The specific gravity of the cables with parachutes so little exceeds that of water, that they readily float under the action of the current, and so they can be given a course of from 1300 to 1650 feet. The practical diameters of the parachutes range between 2 feet and 6½ feet. The cable can work under the ice, it is unaffected by wind or waves; and as it is perfectly flexible and can be sent to any depth, no impediment is offered to navigation beyond the space occupied by the barges. The whole apparatus can be taken up in an hour for removal to another part of the river. The first cost of the apparatus is small, but the renewal of the cables and parachutes forms a heavy charge, as they are reckoned to have a minimum life of only four months.

The author devised an arrangement of parachutes to utilise the power of a river abroad, where the conditions were not favourable to the employment of turbines or water wheels, and where he had to rely on the velocity of flow instead of on the head of the river.

UTILISING THE TIDES.

The tides afford an enormous source of energy, but practical difficulties prevent their utilisation except to a limited extent. Even where the tidal range is large, as in a river like the Severn, it must be remembered that to utilise the energy by

impounding the water during flood tides, and by passing it through turbines, to produce rotary motion during ebb tides, the large theoretical power that is represented by the difference of level would only be available practically for a very short period four times a day. Turbines require a fairly constant head, but even by impounding the flood tides in more than one receiver, the head would be ever varying with springs and neaps, ebb tides and flood tides. Where the dam that is required to impound tidal water serves also as a roadway to connect the districts on both sides of the creek or estuary, the cost of its construction may be justified, when it would not be so if it was only made to impound water for power purposes. The author some years ago reconstructed an old causeway at Eling, near Southampton Water, and impounded tidal water which was utilised by a mill there. In this case the dam afforded a much-needed means of communication between two districts. At Pembroke similar roadways exist which impound the tidal water in the upper portions of two of the creeks of Milford Haven, for utilisation by mills erected there.

THE GIRARD-BARRÉ HYDRAULIC RAILWAY.

M. Barré has carried to a practical success an idea that occupied the attention of M. Girard many years ago, when he was perfecting the turbine with which his name will be always associated. The project was to construct a vehicle with a smooth bottom that would be in contact with a flat surface upon which it could slide. By directing a current of water under pressure between the two surfaces, the tendency will be both to keep them apart and to cause motion in the direction of the current by which the vehicle would be propelled. A successful illustration of this principle was afforded at the Paris Exhibition in 1889, where a tramway was shown in operation. The vehicles were supported on

slides, resting and moving on plate rails having a broad, even surface. A pipe fitted to the slide enabled a current of water at 150 lbs. per square inch to be directed between the two surfaces, thus preventing metallic contact by a thin film of water. The under sides of the carriages had bucket racks attached to them, like troughs fitted with cross blades, against which was directed the current of water from the main, and so caused the propulsion of the carriages. The stream of water was controlled by valves, by which the speed could be varied, or by shutting off the supply the water-film disappeared, and the metallic contact between the surfaces of the slides and rails provided a brake.

M. Barré stated that the water required to propel the train was 8 gallons per ton per mile. The line, which was 500 feet in length, having a fall at each end, was traversed by the carriages in half a minute. The mechanical details were worked out with great ingenuity, and the system was quite deserving the interest that was taken in it.

POWER CO-OPERATION.

The concentration at one or more points of the power necessary for the supply of water for domestic purposes (in the same way as gas and other requirements of daily life are produced from central stations) has suggested the desirability of developing at one establishment the power that is requisite to actuate machines at work in an area within reach of such centre. The principle has been termed by the author "Power Co-operation," and is now well recognised, having been extensively adopted. The facility with which power can now be transmitted to great distances, enables the co-operation of many power-consumers to be brought about. Bramah realised its feasibility in the following characteristic letter, which was written by him to Robert Mallet in 1802.

Referring to the hydraulic press, Bramah wrote:—"I think much might be done in Ireland in the press way if the excellence of the principle was but known; I have also now applied it with the most surprising effect to every sort of crane for raising and lowering goods in and out of warehouses. So complete is the device, that I will engage to erect a steam-engine in any part of Dublin and from it convey motion and power to all the cranes on the quays and elsewhere, by which goods of any weight may be raised at one-third of the usual cost. This I do by the simple communication of a pipe, just the same as I should do to supply each premises with water. I have a crane on my own premises which astonishes every person to whom it has been shown—as they see the goods ascend and descend fifteen or twenty times in a minute to the height of 18 or 20 feet, and at the same time it is impossible for any person unacquainted with the principle to discover how, or where the power comes from. I also show them pumps raising water with huge force, and a press squeezing wood, etc., to atoms, and not the smallest discovery can be made of the cause. I believe I shall have all the cranage of the London wet-dock warehouses to undertake, which will be the grandest job perhaps ever done."

Many years ago the author promoted a Hydraulic Power Co-operative undertaking in Manchester, and the late Sir W. Fairbairn wrote in regard to it as follows:—

"Your proposal to erect steam-engines and lay down pipes for the purpose of working accumulators for supplying hydraulic power to different localities of the city of Manchester, seems to have several advantages over the system now in use in the different warehouses where steam is employed. In the first place, it would remove steam-engines and boilers from the premises, lessen the risk from fire and boiler explosions; and secondly, it would supply the necessary power to work cranes, hoists, hydraulic presses, etc., in those depôts on principles of increased security."

MANCHESTER HYDRAULIC POWER.

In 1891 the Corporation of Manchester obtained an Act of Parliament to supply water under pressure for such purposes as water-power is applicable. In 1894 an installation was carried out, and has been in successful operation since. In a Corporation report of 1901 the works are thus described:—

"There are two hydraulic pumping stations; one is situated in Whitworth Street West, Oxford Street, adjacent to the Rochdale Canal, and the other adjacent to an arm of the same canal in Pott Street, Ancoats.

"The Whitworth Street West pumping station contains six sets of powerful pumping engines, each capable of delivering into the mains 230 gallons of power water per minute; five large steam boilers, fitted with mechanical stokers, economisers, coal and ash conveyers, etc., of the most approved description.

"The Pott Street pumping station only contains at present four sets of pumping engines, but provision has been made for two additional sets of engines, which will be erected when the increasing demand for the supply of power renders it necessary. The installation at this station is in other respects of the same capacity as that in Whitworth Street West.

"The reservoir of power consists of four large accumulators, loaded to a maximum pressure of 1120 lbs. per square inch, thus producing the same effect as if large supply tanks were placed at an elevation of over 2500 feet above the ground level.

"The power water is maintained in the mains at a pressure of 1000 lbs. per square inch, and is available day and night, within the area of supply, all the year round, Sundays and holidays included.

"A momentum valve, loaded to 1200 lbs. per square inch, must be fixed on all service pipes exceeding 1 inch internal diameter, such valve to be fixed as near as possible to the back pressure valve inside the building.

"The consumer will pay the Corporation for the power water taken in accordance with the scale of charges hereto annexed, a minimum charge being fixed at the rate of 4000 gallons per quarter for each machine on the consumer's premises; for example :—

	Gallons per quarter.	Charge per quarter. £	s.	d.
Minimum for 1 machine	4,000	2	0	0
,, 2 machines	8,000	3	0	0
,, 3 ,,	12,000	4	0	0
,, 4 ,,	24,000	7	0	0

"The meter rent is charged according to the size of the machine required.

"Power water taken in excess of 300,000 gallons per quarter is charged 2s. per thousand gallons for the excess quantity so taken; and in cases where minimum quantities of 500,000 gallons and upwards per quarter are agreed to be taken, or paid for whether taken or not, the following special terms will be adopted :—

		Price per 1000 gallons. s.	d.
For a minimum of	500,000 gallons per quarter	2	0
,,	750,000 ,,	1	9
,,	1,000,000 ,,	1	6
,,	2,000,000 ,,	1	4
,,	3,000,000 ,,	1	3

"Power water taken for motors running on an average six hours per day throughout the quarter, or not less than 460 hours per quarter, is charged 1s. 6d. per thousand gallons."

HULL HYDRAULIC POWER.

Hull was the first town in which an Act of Parliament was obtained to lay high-pressure hydraulic mains under the public streets for the supply of water-power on the co-operative system, and there the author carried out the first public

hydraulic power installation, which was described in a paper read at the Institution of Civil Engineers in 1877 (Robinson on the "Transmission of Power to Distances").

Since that installation was carried out, the system has been adopted extensively in many towns, and in a paper by Mr Ellington read before the Institution of Mechanical Engineers in 1895 the following summary is given:—

EXISTING HYDRAULIC POWERS WORKS.

Place.	Year of Establishment.	Length of Mains.	Largest Diameter of Mains.	Engine Horse-Power.	Delivery of Water per Week.	Number of Machines worked.	Pressure per sq. inch in Mains.
		Miles.	Inches.	I.H.P.	Gallons.	No.	Lbs.
Hull . . .	1877	$2\frac{1}{2}$	6	250	100,000 to 500,000	58	700
London . .	1884	76	7	3,400	9,500,000	2,300	750
Liverpool .	1888	18	6	800	1,000,000	453	800
Melbourne .	1889	18	6	800	1,500,000	413	750
Birmingham	1891	$3\frac{1}{2}$	6	52	78,000	...	700
Sydney . .	1891	12	6	688	740,000	200	750
Antwerp .	1894	$4\frac{1}{2}$	12	1,000	3,300,000	Turbines at three stations	750
Manchester	1894	12	6	800	1,000,000	247	1,120
Glasgow .	1895	9	7	600	nil.	nil.	1,120

CENTRIFUGAL PUMPS.

For raising large quantities of water a small height, a "centrifugal pump" (which is practically an inverted turbine) is a very suitable form of pump. Appold constructed the first, and it has been the basis of all subsequent ones. In this form of motor it is necessary to bear in mind that the greatest efficiency can be only obtained when it is applied to work under a constant head. The calculations on which the shape and design of the motor are based, show that an equally good result cannot be obtained when the head is variable. A velocity of about 5 feet per second for the flow of the suction and discharge water is generally regarded as that which should be aimed at. The disc friction varies as

the square of the diameter, and the loss due to total frictions increases as the cube of the velocity. Experiments with centrifugal pumps have established an efficiency of about 50 per cent. in the small pumps, and about 70 per cent. in the large pumps. The shape of the curved vanes of the fan materially affects the results, the best form being that in which these are bent backwards. Professor Unwin has shown by his experiments on the "Friction of Disc Rotated in Fluid" (recorded in the *Proceedings of the Institution of Civil Engineers*) the conditions which require to be observed in order to minimise the loss of efficiency in turbines and centrifugal pumps. This loss is largely due to the friction of their disc-shaped surfaces in the water surrounding them. The larger the chamber in which the disc rotates, the greater is the friction of the disc, which is attributable to the stilling of the eddies by the surface of the stationary chamber. The stilled water reacting upon the surface of the disc causes the friction of the disc to be dependent, not only on its own surface, but also on the surface of the chamber in which it rotates.

An interesting paper was read at the Institution of Mechanical Engineers by Dr Stanton in 1903, giving the results of experiments on the efficiency of centrifugal pumps which he had carried out in the Hydraulic Laboratory of University College, Bristol.

He truly says that it is difficult to account for the well-known fact, that although a centrifugal pump is merely a turbine reversed, and therefore, theoretically, should have the same efficiency as the turbine, yet in practice the efficiency of the pump is considerably below that of the turbine, a good turbine converting about 80 per cent. of the potential energy of the water into useful work, whereas the effective work in lifting water by centrifugal pumps rarely exceeds 55 per cent. of the work put into the shaft.

The explanation of this difference seems to be, that whereas the potential energy of the water in the turbine is converted

into kinetic energy with very little loss, in the pump there is considerable waste of energy in converting the kinetic energy of the water leaving the wheel into the potential or pressure form, even when the greatest care is taken to avoid shocks and sudden enlargements. The prejudicial effect of this loss on the efficiency is clear from the consideration that in a radial vaned pump approximately half the work put into the shaft is in the form of the kinetic energy of the water leaving the wheel. The following is from Dr Stanton's paper:—

The methods adopted in pump design to make this loss as small as possible are:—(1) To allow the water leaving the wheel to form a free spiral vortex in the pump casing, the pressure increasing radially outwards according to the known law, until the velocity has fallen to the value obtaining in the discharge pipe, as first suggested by Professor James Thomson. Although this method has been much used, there do not seem to be any published data of experiments on the efficiency of such a free vortex. From a study of the loss of energy in streams flowing in diverging channels the author was led to the conclusion that the efficiency of the vortex could not be a high one, and this was found to be the case.

(2) To discharge the water leaving the wheel into guide passages of gradually increasing area until the velocity is sufficiently reduced in value. This is the method used by Professor Reynolds in the Mather-Reynolds pump. It is clearly not suitable for variable discharges unless the area of the guide passages can be regulated. No results of experiments on the efficiency of guide passages have been published as far as the author is aware.

(3) To recurve the vanes of the wheel at the outlet in a direction opposite to that of rotation, so that the velocity of the water leaving the wheel, which is the resultant of the velocity relative to the wheel and the velocity in common with the wheel, shall be comparatively small, and hence that any dissipation of its kinetic energy in shock will not affect the efficiency of the pump to an appreciable extent. This

was the arrangement adopted by Mr Appold in 1851 in his pump, the efficiency of which far exceeded that of the radial vaned type, and the theory of which has been fully investigated by Professor W. Cawthorne Unwin.

It may be remarked that this reduction of resultant velocity can only be realised in moderately slow-speed pumps. In the case of high-speed pumps it will be generally found that the velocity which the water has in common with the wheel at the outlet is so much greater than the velocity of the water relative to the wheel, that the recurving has very little effect in reducing the velocity of discharge from the wheel.

An objection to this method is, that by recurving the vanes of the wheel we increase the speed at which the wheel must be run to give the same lift, and since the loss of work due to friction varies approximately as the cube of the speed, this will tend to diminish the gain due to diminished velocity of discharge. The superiority, however, of curved vanes over radial vanes, which is undoubted for the case of moderately slow-speed wheels, is not so clearly established for the case of high-speed wheels, the best practice on the Continent apparently being to revert to the radial vaned type.

The general conclusions which he arrived at from the results of his experiments were as follows:—

(1) In high-speed wheels, namely, wheels in which the velocity of the tips of the vanes exceed 40 feet per second, the effect of moderately recurving the vanes at the outlet is beneficial (especially when the water is discharged into a free vortex), the curvature being such that the velocity of flow of water through the wheel is uniform.

(2) Wheels which discharge the water into guide passages give a higher efficiency than those which discharge the water into a free vortex, this advantage being more marked in the case of wheels with radial vanes than in the other type.

(3) The number of guide passages should not be less than four, and the areas at the inlet should be such that the velocity of flow into the passages should be equal to the

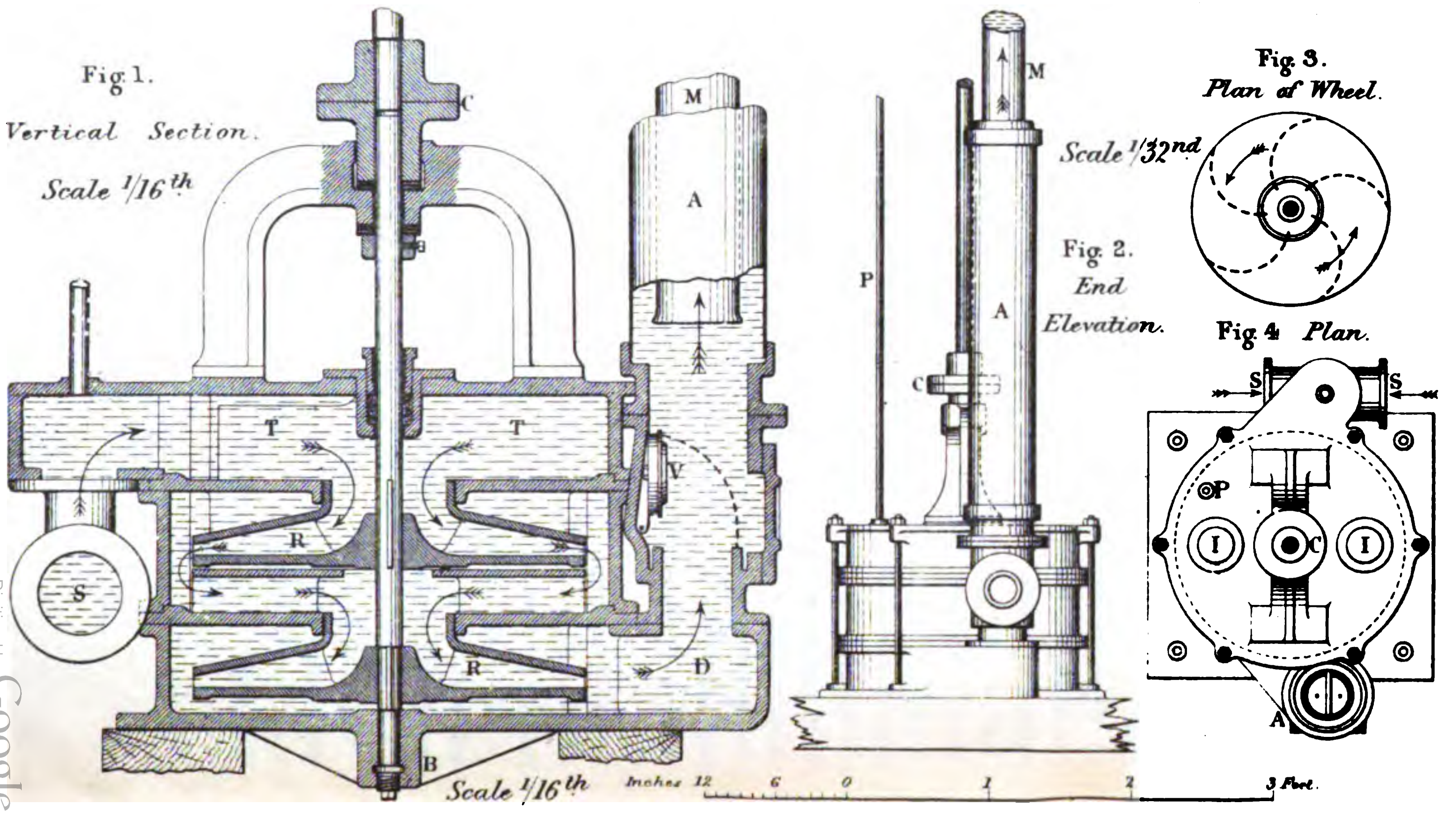
velocity of discharge from the wheel, to avoid losses from sudden changes of velocity.

As regards any modification of the existing design of centrifugal pumps, Dr Stanton suggests that increased efficiency, and considerable economy in material and space occupied, would result in the adoption of a high-speed pump driven direct from the motor, and designed on the principles laid down above. For dealing with very large quantities of water at low lift, no doubt the present slow-speed pump driven direct from a steam engine has great advantages, but for supplying moderate quantities of water at high, or moderately high, lifts, the high-speed motor-driven pump is very suitable. When the simplicity of construction and small cost of centrifugal pumps is considered, it seems remarkable that the use of them should be so limited. This is perhaps due to the impression which has, till recent years, prevailed, that these pumps were useless at other than quite low lifts. Now that their adaptability and satisfactory working at high lifts is being recognised, there seems every reason to suppose that they will come into use in many cases where reciprocating pumps have hitherto been solely employed.

As the speed at which a centrifugal pump should be run increases approximately as the square of the height of lift, the revolving wheel has to overrun the flow in that increasing degree, whilst the effect due to impact falls off with the increasing velocity of the wheel. In low lifts the overrunning diminishes in the same degree, whilst the effect due to impact is increased. To meet the difficulties that arise where centrifugal pumps have to be used for high lifts, and in a space too limited to allow of a single wheel being constructed large enough to give the required velocity, compound pumps have been employed, by which both the size of the wheels and casing, as well as the speed, have been lessened.

IRRIGATING MACHINERY.

COMPOUND CENTRIFUGAL PUMP.



West. Newman Photo.

COMPOUND CENTRIFUGAL PUMP.

An arrangement of pump on the above principle has been successfully carried out by Mr John Richards of San Francisco, and as the compounding of centrifugal pumps has not been much employed, mention will be made of one that was described by him to the Mechanical Engineers in 1888.

Plate 60 shows a compound pump with two revolving wheels R. The driving shaft is coupled to the pump spindle at C, the bottom bearing being at B. A charging pipe P is carried down from the surface above, and the pump is charged either by a steam ejector or an air pump, always at the top of the pit. The charging is not done by water, as foot valves are not employed. The foot of the delivery main M is surrounded by an air-vessel A. The water is drawn by suction into the top chamber T, whence it passes downwards through the two wheels R, and out to the discharge chamber D, through the delivery valve V, and up the rising main M. There are five curved vanes to each of the shrouded wheels, as shown in plan by fig. 3. Besides the double inlets S S, there are two more inlet orifices in the top cover, at I I, shown in plan by fig. 4, for attaching two more suction pipes, but the four inlets are not often required. The air-vessel A is desirable for deep pumps.

The employment of direct-acting centrifugal pumping engines to the salvage of ships and their cargoes has engaged the attention of Messrs J. and H. Gwynne for many years, and their "Invincible" plant is largely used.

Fig. 71 represents a machine of the latest design used in salvage work. It has inverted suction and delivery branches 18 inches in diameter, and will deliver 1800 tons of water per hour against a head of 30 feet. The engine is placed below deck, and can be worked by the engineer in charge of the propelling engines. The suction main is carried fore and aft underneath the deck, with the ends, which swivel, carried

through the deck. The pump can draw the whole of its water from either end of the main, or part from one end and the

Fig. 71.

remainder from the other, the connections being arranged so that the flow can be stopped on one side and taken in at the other. Thus by regulating the valves the sunken vessel can be raised on an even keel.

WATER WHEELS.

In considering the application of water to wheels, the variation of level of the water determines the character of the wheel to be employed. The rise in the stream, and in the level of the water for a given width of wheel, is sometimes greater than can be utilised in the open bucket of an overshot wheel. A variation of level of 2 feet, and a velocity of the periphery of the wheel of 5 feet, per second, are the usual limits. When the water is received by the wheel below the summit (generally between the axis and the lowest point), it is called a "Breast Wheel." In this case the supply is regulated by an adjustable sluice, over which the water flows to vanes on the wheel, which are substituted for buckets. A channel of brickwork or stone surrounds the wheel, and in this the vanes move. The water filling this channel acts by its weight in turning the wheel. The efficiency of an overshot or breast wheel sometimes reaches 75 per cent., but a lower efficiency of about 65 per cent. is a safer estimate, unless the wheel is very well designed and constructed.

In the ordinary overshot wheel the open buckets of wood or iron are shaped so as to prevent the water shooting over the wheel. This is also obviated by making the capacity of the bucket sufficient to hold about three times the volume of water discharging into it. The buckets are placed between two shrouds, and the power acting on the wheel is measured by the volume of water and the height through which it falls. If F is the net fall in feet, Q the weight of water per second in pounds, then the gross horse-power acting on a wheel will be—

$$\frac{QF \times 60}{33,000}$$

In the "undershot" water wheel the water acts by its momentum at the bottom of the wheel. When small falls of 6 feet or so, or rapid currents, have to be utilised, the under-

shot waterwheel, as perfected by General Poncelet, is a most efficient prime mover. Beyond that fall the wheel has to be large and costly to give much power, and a turbine is preferable. Even when the undershot waterwheel is working under favourable conditions, at least one-half of the energy due to the fall is lost. The water impinging on the floats imparts some of its energy to the wheel, but it loses part through eddies and breaking up. After it has acted on the floats again, it passes away from under the wheel with a velocity at least equal to that of the wheel, all of which velocity represents lost energy. About 25 per cent. of loss may be attributed to each of these causes, although in good undershot wheels 60 per cent. of efficiency is possible.

Poncelet adopted the following rules as enabling the best results to be obtained:—The water should impinge on the curved buckets at the bottom of the wheel at an inclination of 1 in 10. The diameter of the wheel should be twice the depth of the fall. The velocity of the periphery of the wheel should be arranged to be 55 per cent. of the velocity due to the head, measured to the centre of inlet. The fall and volume of water being known, the power of a wheel is determined thus, taking 60 per cent. of efficiency:—

Q = Volume of water in cubic feet per minute.
HP = Effective horse-power.
F = Fall in feet.
530·5 = Cubic feet of water per minute falling 1 foot $= 530·5 \times 62·2 = 33{,}000$ ft.-lbs. per minute = 1 horse-power.
c = efficiency.

Then

$$HP = \frac{Q \times F \times c}{530·5}$$

If

Q = 3000 cubic feet per minute.
F = 4 feet.
c = 60 per cent. = ·6.

$$HP = \frac{3000 \times 4 \times ·6}{530·5} = 13\tfrac{1}{2}.$$

In America the "Pelton" waterwheel is reported to have an efficiency as high as 80 per cent., owing to the substitution of cups for flat floats which are attached to the circumference of a wheel. The water is delivered to the wheel through a nozzle of from 1 inch to 2 inches diameter, and the water impinging on the wheel and striking the cups in the middle, is deflected to both sides equally. The water is thus not broken, but spreads and exhausts the whole of its energy in the cup. The Pelton wheel is in fact an "impulse" turbine, hereafter referred to.

A "Chinese" (or "Scoop") wheel is simply an overshot water wheel with reversed motion, by which water is caught up in the buckets of the wheel as it revolves, and is raised to a height nearly equivalent to the diameter of the wheel. For low lifts of about 10 feet, and for large volumes of water, this form of pump has an efficiency of upwards of 80 per cent. The diameter is usually from four to five times the height of the lift, and the speed of the periphery should be about 8 feet per second. This kind of motor is adapted to the draining of fen lands. In California the Chinese pump is extensively employed for low lifts for irrigation purposes. It consists of an endless band (generally a pair of ropes) passing over pulleys at the top and bottom of a slope; the bands carry a series of wooden floats or cross-bars fixed to the outer face and travelling in an open trough, by which water is raised from a stream at a low level and is delivered into carriers for distribution at a higher level. For slopes of about 20°, and for lifts of about 6 feet, this is a very economical method of raising water.

Mr Wilfrid Airy has designed an "Archimedean Screw" pump for lifting fluids, which illustrates the great efficiency obtainable from a motor which is designed to avoid loss of energy from eddies or shocks in the translation of the fluid. A description of this pump was given to the Institution of Civil Engineers in 1871. It consists of a rotating cylinder having a central core and one or more spiral passages. It

works in a frame at an angle of 30° to 45° with the horizon, and the velocity of rotation is about 3 feet per second, measured on the periphery of the cylinder. The lower end is placed in the water to be raised, and the upper end is attached to the delivery. In the working of a well-constructed Archimedean screw pump on this plan, an efficiency as high as 85 per cent. is obtained. The feature in this motor is that the spiral threads are made on the "developable" system, or that by which a curved surface can be unwrapped, laid flat, and made into a plane.

TURBINES.

In the old "Barker's Mill" or "Reaction Wheel," water passes downwards through a vertical tube, which forms the axis of a horizontal tube, having holes at its extremities through which the water issues. This produces a rotative action, but it also causes the water to have a rotary velocity after leaving the tubes of the reaction machine, which involves a loss of power. This attracted the attention of Fourneyron, and led to his inventing the "turbine." By means of guide blades fixed in an external case, he gave the water a forward motion before it entered the wheel or internal case which revolved on the axis of the machine. This resulted in the water passing out of the machine at right angles to the axis, without a backward velocity, thus avoiding the corresponding loss of energy.

Turbines are classified into radial, axial, and combined or mixed flow. In radial turbines the water passes through the wheel in a direction at right angles to the axis of rotation. In axial turbines the water passes through the wheels in a direction parallel to the axis of rotation. In the other cases both the radial and the axial are combined. Some turbines work with all the parts under water, and these are called "Reaction" turbines, which are the best type for low and

varying falls. Other turbines are constructed with the buckets only partly filled with water, the rest of the space having air in it. These are termed "Impulse" turbines, which are not suitable for very low or varying falls. In both cases there are guide vanes to direct the entry of the water to the buckets of the wheel. The machine devised by Fourneyron forms essentially the basis of the numerous turbines which have been subsequently invented by Jonval, Professor Thomson, Schiele, Girard, and others. In well-constructed turbines the loss of energy due to velocity after the water leaves the machine varies from 5 to 8 per cent. The loss from skin friction depends on the size and form of the machine.

The power of a turbine can be calculated by the method given for water wheels "*c*," varying from ·75 to ·80.

A series of experiments by Mr Lehmann on thirty-six turbines, varying from 1 to 500 h.-p., led to the following estimate of losses:—

Loss per cent. due to	Axial Flow.	Outward Flow.	Inward Flow.
Hydraulic resistances, . .	12	14	10
Unutilised energy, . . .	3	7	6
Shaft friction, ...	3	2	2
Total, . . .	18	23	18
Efficiency, . .	0·82	0·77	0·82

Mr Steiger, in a paper read at the Institution of Electrical Engineers in 1896, gave the following table of the efficiency of water wheels and turbines, with the fall for which they are adapted:—

Fall in Feet.	Efficiency of Water Wheel.	Per cent.	Efficiency of Turbine per cent.
1 to 5	Ordinary undershot, . .	25 to 30	70 to 75
	Poncelet, ...	65 to 70	
	Sagebien, ...	65 to 75	
5 to 8	Low breast, ...	30 to 50	75 to 80
8 to 15	High breast, ...	60 to 75	75 to 80
15 to 50	Overshot wheel, . . .	65 to 75	75 to 80
About 50	Pressure engine, . . .	75 to 85	75 to 80

These figures show that the smaller the fall is, the greater is the gain in power over the old-fashioned water wheels. Although the smallest fall which would probably be utilised by a turbine is at least 2 feet 6 inches, useful power can be obtained with a fall even of about one foot, if the turbine is suitably constructed.

A higher speed can be obtained on turbines that work with low falls, if the upper body of the wheel, which receives the water, is made smaller in diameter than was the practice in the past, and by increasing the diameter and discharge area of the buckets on the lower part of the wheel.

The Waverley Company of Edinburgh make a type of turbine for low falls, which has a very good efficiency. It has been found advantageous to work the wheel partly drowned when the fall is as low as about 5 feet, the normal tail water being level with the inside of the flume containing the turbine. In their 36-inch vertical shaft turbine the bottom of the wheel is three inches larger than the body of the wheel. There are sixteen buckets, the discharging area of which is 725 square inches. There are eighteen ports 17 inches long, having a total area of 631 square inches. This type of wheel works with a head of 5 feet, and develops 20 h.-p. Their larger types include a horizontal one having a wheel 40 inches in diameter, and it develops 100 h.-p. on a 14-feet head, 6 feet of which is worked by suction. In this larger form the shaft is not extended into the discharge bend as in the smaller ones, the thrust being taken on a special design of cross, fitted in the end of the casing. This type is suitable for falls up to 50 to 60 feet. For falls above this, and up to 300 feet, the form of turbine they adopt has only one wheel, but has two discharges, one at each side.

At Schaffhausen in Switzerland a great hydraulic power installation was carried out upwards of thirty years ago, when the power of the Rhine was utilised and transmitted, at first by wire cables, and more recently by electricity, over considerable distances. This was the largest installation in

Europe, but is now exceeded by the 9000 h.-p. of Tivoli, more recently "harnessed" for transmission to Rome. At Bellegarde, a little town in France near the Swiss frontier, a water-power installation was carried out on the Rhone, following the example of Schaffhausen. Six turbines of 630 h.-p. each, working under a head of 46 feet, are employed to pump water to the upper level of the town above and to distribute power. Zurich, Geneva and other places in Europe and elsewhere have utilised water-power, but the largest installation in the world is at Niagara, referred to hereafter.

FOYERS WATER POWER.

The British Aluminium Company have carried out the only installation of water-power of any magnitude in the United Kingdom, by utilising the water derived from the river Foyers. The Company obtained the water rights over about 100 square miles of country, which forms the gathering ground supplying the river. The greater part of this land is at an elevation of from 600 to 2000 feet above Loch Ness, and the water from the whole area passes by lochs and rivers and discharges over the Falls of Foyers. By the construction of dams and embankments, a continuous loch has been formed between five and six miles long and about half a mile in width. The water is conveyed through a tunnel 8½ feet in diameter cut in the solid rock, to a penstock chamber, whence by separate cast iron pipes it is delivered, under a head of 350 feet, to turbines at the aluminium factory, which is built on a level piece of ground on the shore of Loch Ness.

The installation consists of seven "impulse" turbines of 700 h.-p. each, the wheels of which are 10 feet in diameter, attached to vertical shafts at the upper ends of which are dynamos. To develop the full power of the turbine it has

to work at a velocity of 140 revolutions per minute. Its efficiency is rather more than 75 per cent. The water used by each turbine is 1200 cubic feet per minute. The electrical energy developed by the dynamos is utilised for the production of aluminium and carbide of calcium by means of the electric furnace.

NIAGARA FALLS.

In a paper read at the Institution of Civil Engineers in 1877 the late Lord (then Sir William) Armstrong stated that the Falls of Niagara had been estimated by Sir William (then Dr) Siemens (who had visited the Falls the previous year) to "be capable of yielding as much power as would result from the combustion of the entire quantity of coal now raised throughout the world, if the whole were applied with average economy to the service of steam engines; and it is not impossible that at some future period that mighty cascade may to a great extent be subjugated for the production of transmissible power to supply the requirements of a widespread manufacturing population. It would be rash to pronounce even such an undertaking as this to be too great for the future enterprise of America."

Lord Armstrong lived to see the accomplishment of this undertaking. *Cassier's Magazine* for July 1895 gave a complete history of these Falls, and a detailed description of the work that had been carried out to utilise, or to "harness" them, as it has been termed. The late Sir William Siemens in his presidential address to the Iron and Steel Institute in 1877, pointed out how the power obtainable from the Falls could be transmitted to distances by electricity, and his anticipations have been fully realised.

A charter was granted in 1886 to the "Niagara River Hydraulic Power and Sewer Company of Niagara, N.Y.," whose scheme was to construct a tunnel about 1½ miles long to

convey the water back to a district along the shores of the upper Niagara river, to be used there by millowners. In order to carry out this undertaking the "Cataract Construction Company" was formed for the purpose of constructing a tunnel which commences at the river above the water level below the Falls, and passes under the city of Niagara to a large tract of land that has been acquired by the Company, near the river bank above the city. The tunnel is capable of conveying water representing 100,000 h.-p., or about 3½ per cent. of the whole flow. The shape of the tunnel is that of a horseshoe, 19 feet wide by 21 feet high, inside the brickwork which lines it. The base of the tunnel, at its discharge point below the Falls, is 205 feet below the sill of the head gate at the entrance of the main canal from the river above the Falls. Of this fall 140 feet will be available, the rest being taken up by allowance for clearance from the wheel pits, by the fall (of 36 feet per mile) of the lateral tunnels leading to the main discharge tunnel.

At the outset the Power Company adopted turbines with vertical shafts, and the same were used by the Niagara Paper Company, who utilised part of the power. Considerations of economy in regard to rock excavation per horse-power developed, influenced the design of the turbine with a view to having the greatest power for each unit. The Power Company, at the outset, adopted 5000 h.-p. for each turbine at the central power station, whilst the Paper Company adopted 1100 h.-p. for a group of turbines which were of the Jonval type, designed and built by R. D. Wood & Co. of Philadelphia. The turbines of the Power Company were of the Fourneyron type, designed by Faesch & Piccard of Geneva, and built by the Morris Company of Philadelphia. Two of these Fourneyron turbines are placed so that one set is inverted and vertically over the other in order to neutralise weight on the stop or bearing. They will discharge 430 cubic feet per second, and acting under 136 feet of fall from the surface of the upper water to the centre between the upper

and lower wheels, they will make 250 revolutions per minute. This at 75 per cent. efficiency represents 5000 h.-p. The guide-wheel has thirty-six buckets, and the turbine wheel has thirty-two, the buckets being thickened in the middle, which is the most approved form. The turbine wheels are made of bronze, the rim and buckets forming a single casting. The shaft is a steel tube 38 inches in diameter, except at points where it passes the journal bearings or guides, at which it is 11 inches in diameter and is solid.

In 1900 the Power Company ordered from Messrs Escher, Wyss & Co. of Zurich a turbine of 5500 h.-p. to run at 250 revolutions per minute, the available head of water being from 144 feet to 161 feet. This turbine is of the Francis type, with only one wheel of 5·25 feet diameter, consisting of a single casting of manganese bronze. Regulation is effected by means of an annular case, which is movable in a vertical direction between the wheel and the guide vanes by means of two vertical rods. The water enters the case through a tube 7·44 feet diameter. The pressure upon the bottom footstep of the vertical shaft is relieved by means of water under pressure. The regulator is of the oil-pressure type with Servo-motor. The balancing of the rod acts upon a two-armed lever and thence upon the piston of the Servo-motor, which has merely to open the turbine, while the closing is effected by the balance-weight and the weight of the parts of the apparatus. Below the regulator valve there is another valve actuated by electricity, and controlled from a switchboard. There is also an arrangement of hand-gear regulation which can be used if necessary.

The extent to which the Falls are being already utilised is shown by the statement that the average load throughout the month of September 1902 was upwards of 47,000 h.-p. Part of this is used for industrial purposes, the rest is applied to electric street railways, to mechanical power, and to electric lighting for a distance of forty miles. The present arrangements for transmission are three-phase current at 22,000 volts,

which it is understood will in the new line be taken up to 40,000 volts, or even 60,000 volts for long-distance lines.

In *Cassier's Magazine* for December 1903 the various steps which the Company have taken to utilise the enormous power which they had successfully brought into practical use are recorded. These may be briefly described as consisting of three power-houses. The first has reached its capacity of 50,000 h.-p. The second, having a capacity of 55,000 h.-p., is approaching its limit. The third, of 110,000 h.-p., is being constructed on the Canada side of the river to operate in conjunction with the first two, thus making a total of 215,000 h.-p. The turbines for the second power-house, Mr Clemens Herschel states, have been constructed more up-to-date than those which were put down in the first power-house, and are consequently more efficient. The turbines (consisting of eleven 5000 h.-p. machines) for the second house were built by the J. P. Morris Company of Philadelphia, from designs of Escher, Wyss & Co. of Zurich, the power being utilised on the lands of the Niagara Falls Power Company, the Union Carbide Company alone taking 15,000 h.-p. The whole of these eleven units are now completed.

The third house is situated in the Queen Victoria Niagara Falls Park, about half a mile above the Horseshoe Falls, and will supply power in both Canada and the States, when the other two installations have reached their capacity for supplying power. The water is taken in from the river through a short canal, is discharged through penstocks to the turbines, and passes away through a tunnel to the river.

The turbines for this house are to be of a capacity of 10,000 h.-p., the largest that have as yet been constructed, and there will be eleven of them. These large turbines will occupy but little more space than those of 5000 h.-p., effecting a great reduction in length of wheel pit and power-house for a given output. These turbines have been designed, and are being constructed, by Escher, Wyss & Co.

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